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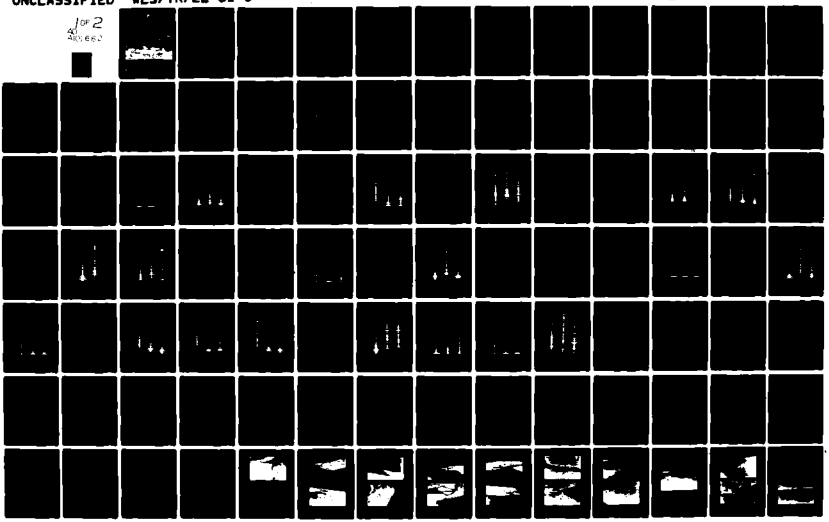

TECHNICAL REPORT EL-81-5

FIELD SURVEY OF HEAVY METAL UPTAKE BY NATURALLY OCCURRING SALTWATER AND FRESHWATER MARSH PLANTS

by

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A natural marsh heavy metal survey was conducted to establish a baseline for comparison to plant concentration and uptake data from contaminated and perturbated sediments.

Extensive field sampling of natural marshes was conducted along the East and gulf coasts of the United States, and along the shores of the Great Lakes. *Spartina alterniflora* was collected from the saltwater marshes and *Cyperus*

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20. ABSTRACT (Continued).

species were collected from the freshwater marsh areas.

Results indicated that, in the saltwater marsh, manganese and zinc concentrations were slightly lower than those previously determined in greenhouse and disposal site studies with contaminated sediments, while the concentrations of the remainder of heavy metals were similar. Calculation of total uptake values indicated that only cadmium may be of concern.

Cadmium levels in *Cyperus* species in naturally occurring marshes were similar to those of a greenhouse flooded (reduced) environment. Iron and manganese were generally present in lower concentration in the natural marsh than in the greenhouse plants grown on contaminated sediment, while the remainder of the heavy metals examined were present in higher concentrations.

This investigation forms the basis for the conclusion that marsh plants grown on contaminated dredged material in a flooded environment do not bioconcentrate excessive or even significantly higher levels of toxic metals than those same plant species in naturally occurring marshes.

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PREFACE

This investigation was conducted by the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., during 1978-1980 by Drs. John W. Simmers, Bobby L. Folsom, Jr., and Charles R. Lee and Messrs. Derrick J. Bates, Thomas C. Sturgis, Dewey S. Sandberg, Roger D. Brock, and R. Glenn Rhett of the Contaminant Mobility Research Team, under the general supervision of Dr. R. M. Engler, Chief, Ecological Effects and Regulatory Criteria Group, Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division (ERSD), and Dr. John Harrison, Chief, EL. Assistance was also received from several other members of the ERSD. Funding for the study was provided by the Dredging Operations Technical Support (DOTS) Program, Mr. C. C. Calhoun, Jr., Program Manager.

Dr. C. B. Loadholt, Professor of Biometrics, Medical College of South Carolina, assisted the authors on statistical matters.

This report is the fourth in a group of reports addressing bioconcentration of heavy metal contaminants by marsh plants.

Helicopter landings for plant collections at selected locations within the respective refuge areas were arranged by the following: Mr. Russ Ernest, Manager, Area 3, Region 4, U. S. Fish and Wildlife Service (USFWS); Mr. Frank Johnson, USFWS, Aransas National Wildlife Refuge; Mr. Russ Clapper, USFWS, Anahuac National Wildlife Refuge; Mr. Ron Bisby, USFWS, San Bernard and Brazoria National Wildlife Refuges; Mr. Donald Hankla, Manager, Area 1, Region 4, USFWS; Mr. William Hickling, Manager, Area 2, Region 4, USFWS; Dr. John Bozeman, Georgia Department of Natural Resources; Mr. Martin D. Perry, Acting Project Leader, Savannah Complex of Refuges; Mr. Larry Nygren, USFWS, Morton, Amagansett, Conscience Point, Target Rock, Brigantine, and Barneget National Wildlife Refuges; Messrs. Phil Feiger and Charlie Blair, USFWS, Eastern Neck National Wildlife Refuge; Messrs. Bill Julian and Matt Kershbaum, USFWS, Martin National Wildlife Refuge; Mr. Dell Kidde, USFWS Area 5; and Mr. William Sherman, Superintendent, Metro Beach, Metropark, Mt. Clemens, Mich.

The Commanders and Directors of the WES during the study and the preparation and publication of the report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

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FIELD SURVEY OF HEAVY METAL UPTAKE BY NATURALLY OCCURRING SALTWATER AND FRESHWATER MARSH PLANTS

PART I: INTRODUCTION

Background

1. The U. S. Army Corps of Engineers is required to dredge more than 205 million cubic metres of sediment from the waterways of the United States each year to maintain navigation channels (Water Resources Support Center 1979). Disposal of this amount of sediment is of immediate concern. Marsh creation from dredged material has received increased public support in recent years. However, contaminants such as toxic metals may move from the substrate through plant uptake and seriously affect biological components of the ecosystem. The heavy metals that are considered contaminants when present in high concentrations in dredged material are also present naturally in soils and sediments, presumably in lower concentrations.

2. Research under the Dredged Material Research Program (DMRP) and the Dredging Operations Technical Support Program (DOTS) has documented the uptake and bioconcentration of certain heavy metals in the common marsh plants *Spartina alterniflora* and *Cyperus esculentus* when these species are grown on contaminated dredged material. However, no complementary data base exists for the same species grown on naturally occurring sediments. A need exists to develop a data base that will serve as a baseline for evaluation of contaminant uptake by plants grown on contaminated dredged material being used for marsh or upland habitat development. The establishment of this natural marsh heavy metal baseline is necessary to relate plant uptake data from dredged material to naturally occurring levels of heavy metal uptake.

Purpose and Scope

3. This study is the fourth in a group of studies addressing the

bioconcentration of heavy metal contaminants via marsh plants. In a previous greenhouse hydroponic study, Lee, Sturgis, and Landin (1976) found that *Cyperus esculentus, Spartina patens, S. alterniflora,* and *Distichlis spicata* accumulated heavy metals from the hydroponic solutions. In development of prediction techniques for contaminant mobility, Lee, Sturgis, and Landin (1978) related heavy metal accumulations in *S. alterniflora, S. patens,* and *D. spicata* collected from dredged material disposal sites to the heavy metal content of various chemical extractions of dredged material. The greenhouse study of Folsom, Lee, and Bates (1980) focused on the distinctions between reduced (flooded) and oxidized (upland) contaminated sediments with respect to heavy metal uptake by *C. esculentus* and *S. alterniflora.* Throughout the remainder of this report, these studies will be referenced as the hydroponic study, the disposal site study, and the greenhouse study, respectively. Accordingly, a field survey and sampling study was designed with the following objectives:

a. To determine concentrations of heavy metals in plants from natural marshes along the Atlantic and gulf coasts and around the Great Lakes.

b. To compare the heavy metal concentrations in plants from the above-mentioned natural marshes to those previously found in marsh plants grown on dredged material.

4. The field sampling was based on the plant species used in the greenhouse study. The estuarine marsh plant *Spartina alterniflora* (Loisel.) Merr. was collected along the Atlantic and gulf coasts. This widespread, abundant species took up heavy metals readily during the hydroponic study. In the greenhouse study, *S. alterniflora* accumulated some heavy metals. Locations sampled were limited to the Atlantic and gulf coasts of the United States. Sampling sites included natural marshes located near industrial and urban areas as well as wildlife refuges and National, State, and local parks or natural areas. Sampling was limited to those plants colonizing naturally occurring sediment.

5. *Cyperus* species, *C. esculentus* L., *C. strigosus* L., *C. odoratus* L., *C. erythrorhyzos* Muhl., and *C. Englemanni* Steud., were collected from naturally occurring marsh areas along the United States' shore of

the Great Lakes. *Cyperus esculentus* took up metals very rapidly from hydroponic solutions and was subsequently utilized in the freshwater portion of the greenhouse study. While *C. esculentus* is not the dominant plant in the natural marshes of the Great Lakes, one or a combination of the five similar species mentioned above is present.

Approach

6. Helicopters were used to collect plant leaf samples from naturally occurring colonies of *S. alterniflora* and *Cyperus* species (*C. esculentus* where possible). At each site, four to five composite samples were taken. The samples were collected at maximum vegetative growth and at least half were collected in proximity to previous sediment, dredged material, or plant collection sites for direct comparison. This study was concerned only with plant leaf heavy metal concentrations; therefore, sediment samples were not collected. The plant samples were analyzed for zinc (Zn), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), mercury (Hg), chromium (Cr), iron (Fe), manganese (Mn), and arsenic (As). Plant leaf processing procedures developed in the previous disposal site study were utilized. Heavy metal composition of plants in the natural marsh communities near the data loci of previous studies was also included in the data base in order to compare the contaminant levels in naturally occurring *S. alterniflora* and *Cyperus* species to those determined in the previous disposal site and greenhouse studies.

PART II: FIELD COLLECTION

Location and Documentation of Sites

7. The selection of the natural marsh sites for the field study collections was based on the sources of the plants collected in the disposal site study and the dredged material and sediment utilized in the greenhouse study. Approximately one half of the samples were collected from natural marshes in proximity to the sediment collection areas used in the greenhouse study; the remaining plants were collected from natural marsh areas within 320 to 480 km along the coast overlapping the disposal area sites (Figure 1). Natural marsh areas selected included locations mentioned in the above studies and areas within Federal, State, and local wildlife refuges. *Spartina alterniflora* was collected from the saltwater marsh areas and *Cyperus* species were collected from the freshwater marsh areas.

8. Within each general area (Figure 1), possible natural marsh collection sites were located on U. S. Geological Survey (USGS) topographic sheets, 7.5-min series where possible, and the information transferred to 1:500,000 aeronautical sectional charts. The sectional chart usage improved communication with the charter helicopter pilots, facilitated advanced planning with contractors, and reduced redundant motions in the field. Permissions and clearances were requested for all potential collection areas from the appropriate Federal, State, and local jurisdictional agencies prior to departure.

9. Once the field party reached a possible collection site as shown on the sectional chart, a specific area of collection was chosen and plotted on the corresponding topographic sheet. Photographs were taken of each sample within the collection site. After collection, an aerial photograph was made of each site, looking north at 30- to 45-m altitude (Appendix A). A field sketch was made of each collection site with the locations of the plant samples denoted and the wet and dry areas of the collection site shown. The accompanying field notes included additional information on the features of the collection site. The photographs and

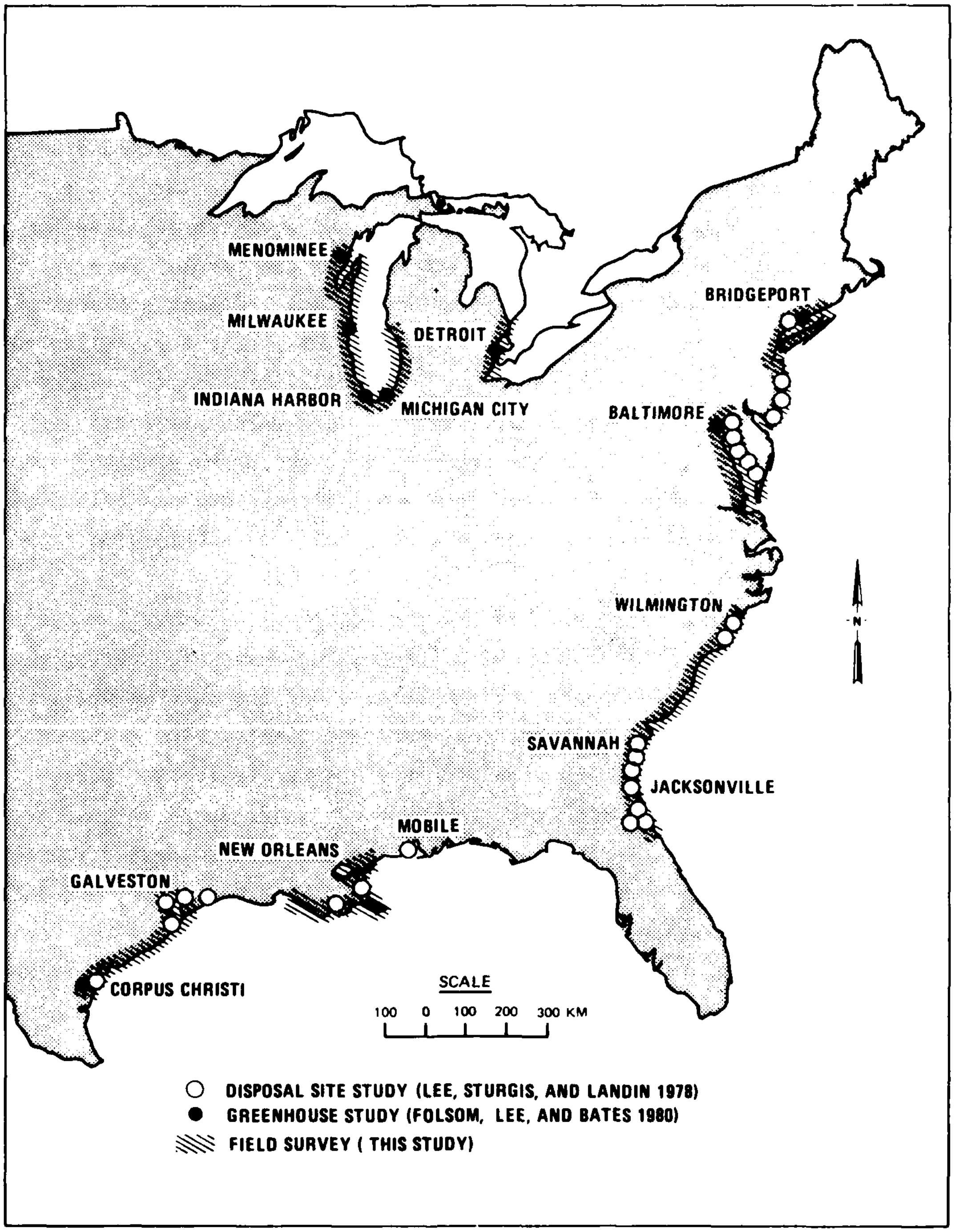

Figure 1. Locations of sediment and marsh plant collections

field sketches were compared to the topographic sheets in order to verify the map location of each site and the locations of the samples within each site. The latitude, longitude, and appropriate USGS topographic sheet for each verified saltwater and freshwater site were recorded (Appendices B and C, respectively).

10. The predicted tidal parameters for each of the salt marsh collection sites were tabulated from Tide Tables 1978 (U. S. Department of Commerce 1977). Information on the prevailing wind direction, by month, at both saltwater and freshwater marsh collection sites (Appendices B and C, respectively) was extrapolated from weather station data from the nearest cities. Weather data were obtained from climatological references of Court (1974) and the Water Information Center, Inc. (1974).

Spartina alterniflora Collection

11. *Spartina alterniflora* was collected from natural saltmarshes. Four samples of *Spartina* were taken from each collection site. Generally, two of the samples, labeled C and D, were taken from flooded conditions and two, A and B, were taken from drier, relatively upland but not necessarily farther inland, areas. Collection times were planned to permit collections to be made at low tide when tidal fluctuation was significant. Each sample consisted of the amount of *Spartina* that could be encompassed by a 28.7-cm square made from a folding carpenter's ruler or 823.7 cm^2. The plants were clipped 5 cm above the ground with Wiss 68 or 607 clippers. The plant material from each sample was placed in a 115-ℓ trash can liner with an acetate label, secured with a twist tie, and placed on ice in an ice chest for shipment within 24 hr to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

12. Collections of *Spartina alterniflora* were made from 63 natural saltwater marsh areas along the U. S. gulf and Atlantic coasts in July and August 1978. Fifteen natural marshes were sampled along the Texas gulf coast on 18 and 19 July 1978 (Figure 2). Corpus Christi sites CC1-CC6 were taken in the vicinity of Nueces Bay, Tex., a site of the previous disposal site studies and the sediment source for the greenhouse

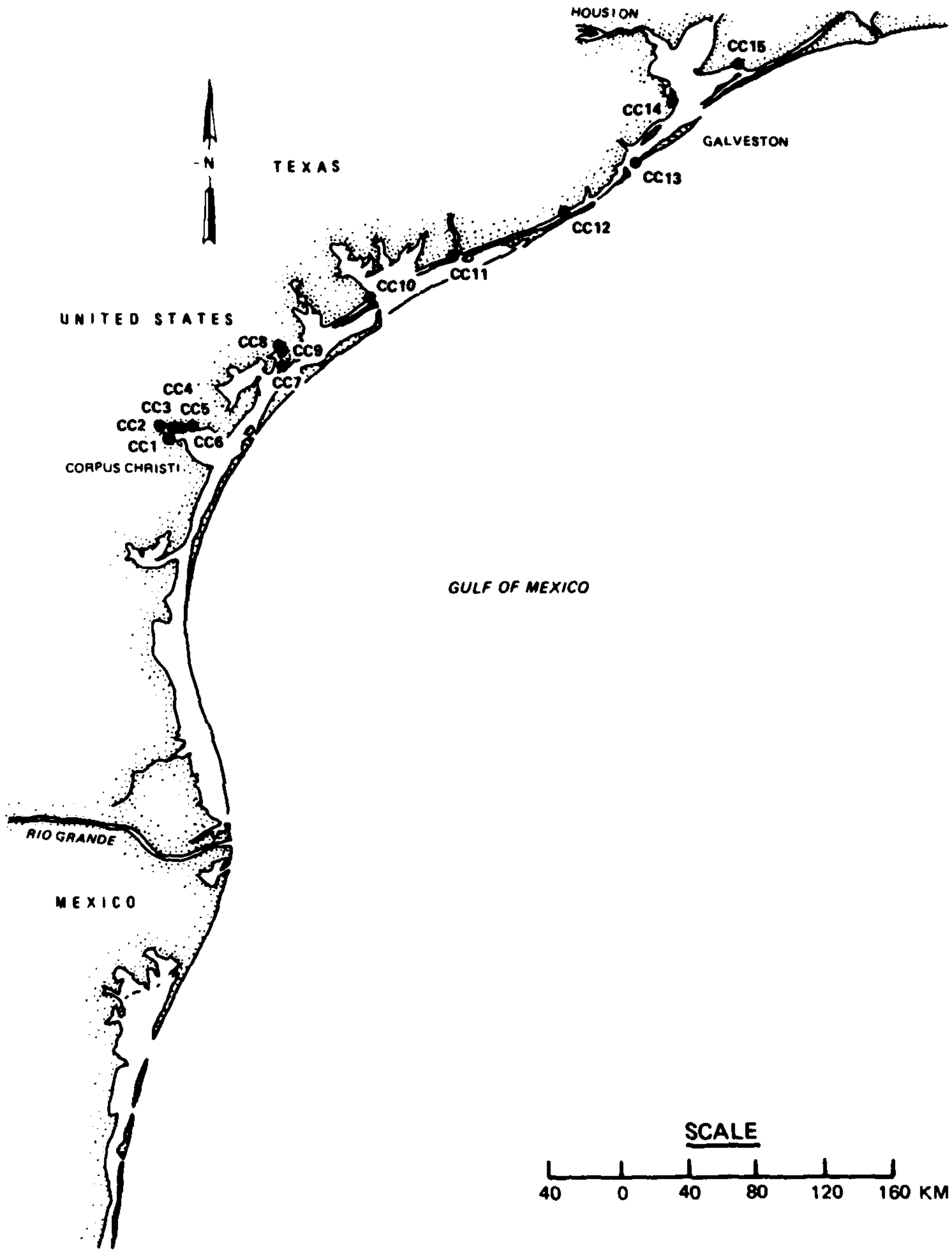

Figure 2. Saltwater natural marsh collection sites, Corpus Christi, CC1-CC15

study. Additional samples were collected north along the coast to the Houston area corresponding to the disposal site study collection areas. Collections of *Spartina* along the Louisiana coast (Figure 3) on

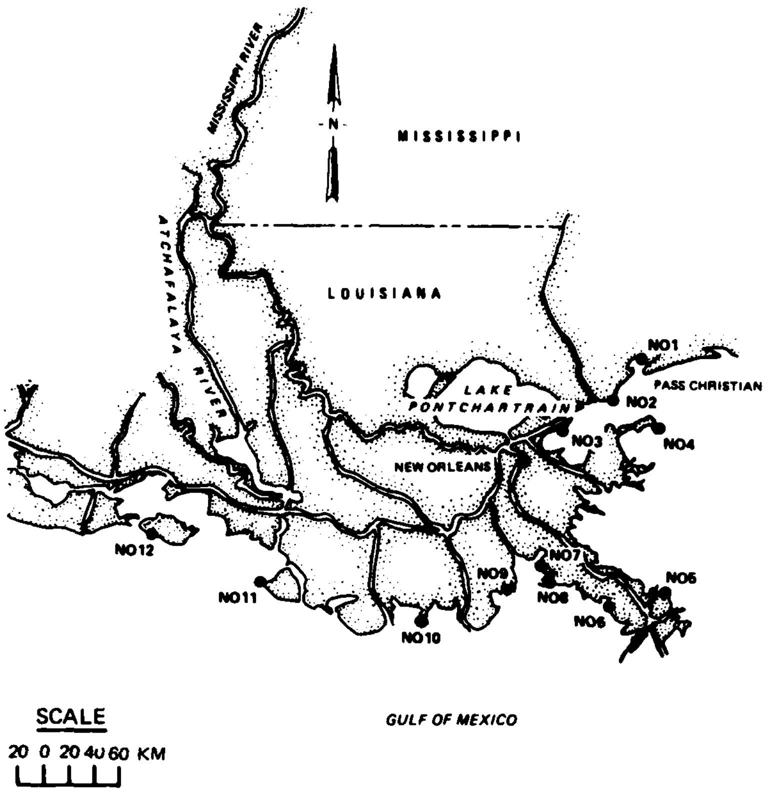

Figure 3. Saltwater natural saltmarsh collection sites, New Orleans, NO1-NO12

20 and 21 July 1978 were made in the same general area used in the disposal site study and in the study of Gosselink, Hopkinson, and Parrondo (1977). The 12 sampled areas in Louisiana were designated NO1-NO12. Twelve sampling areas were also utilized along the Atlantic Coast (JV1-JV12) from Jacksonville, Fla., north to Wilmington, N. C. (Figure 4), on 1 and 2 August 1978. These collection sites were based on the locations of the disposal site study and studies by Broome, Woodhouse, and Seneca (1973) and Dunstan and Windom (1975). In the New York area (Figure 5), collections NY1-NY6 were made in natural marshes adjacent to the Bridgeport, Conn., sediment collection sites of the greeenhouse study and near

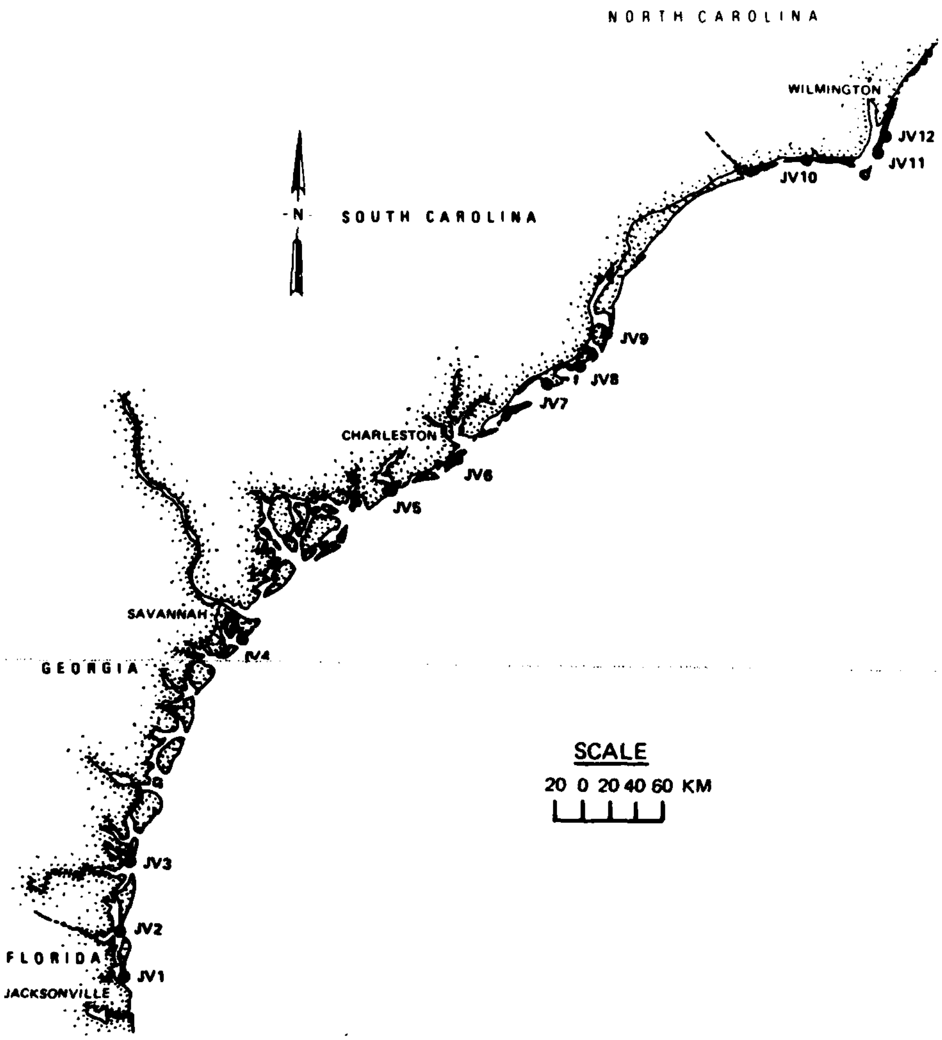

Figure 4. Saltwater natural marsh collection sites, Jacksonville, JV1-JV12

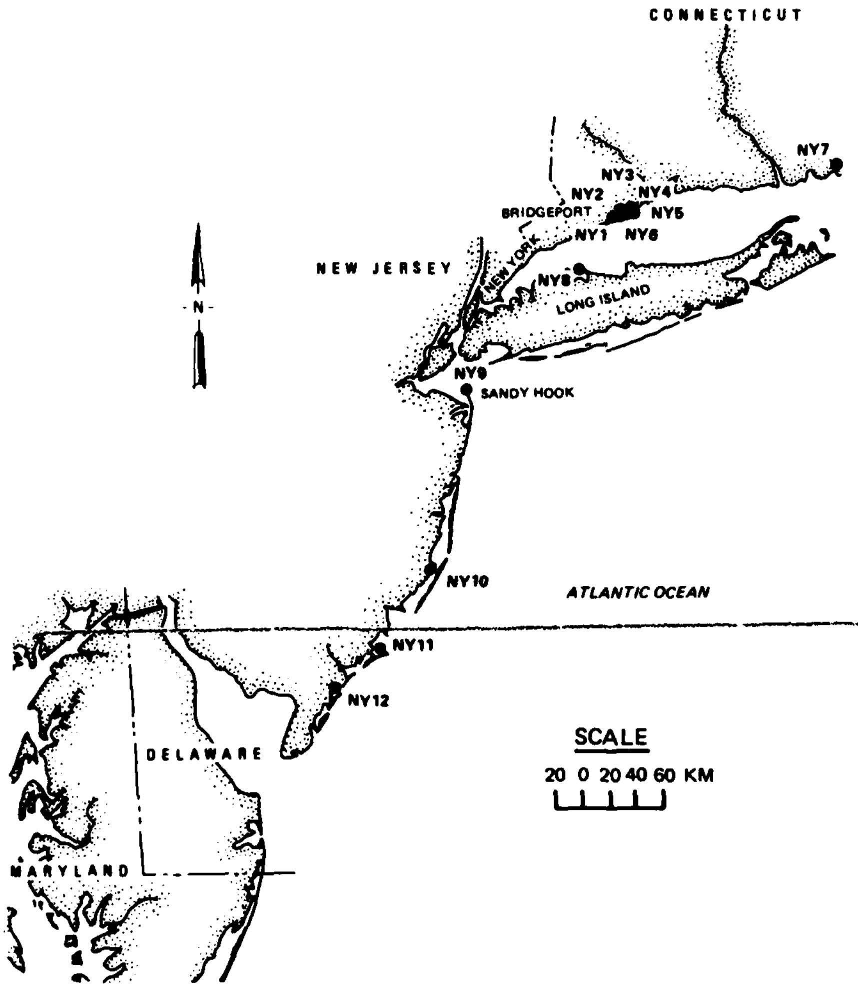

Figure 5. Saltwater natural marsh collection sites, New York, NY1-NY12

a disposal site study area. The remaining marsh collection sites were located along Long Island Sound and south along the New Jersey coast where disposal sites had been sampled. Collections were made 8 and 9 August 1978. The final saltwater natural marsh collections were taken in the Baltimore, Md., area on 10 and 11 August 1978 (Figure 6). Sites

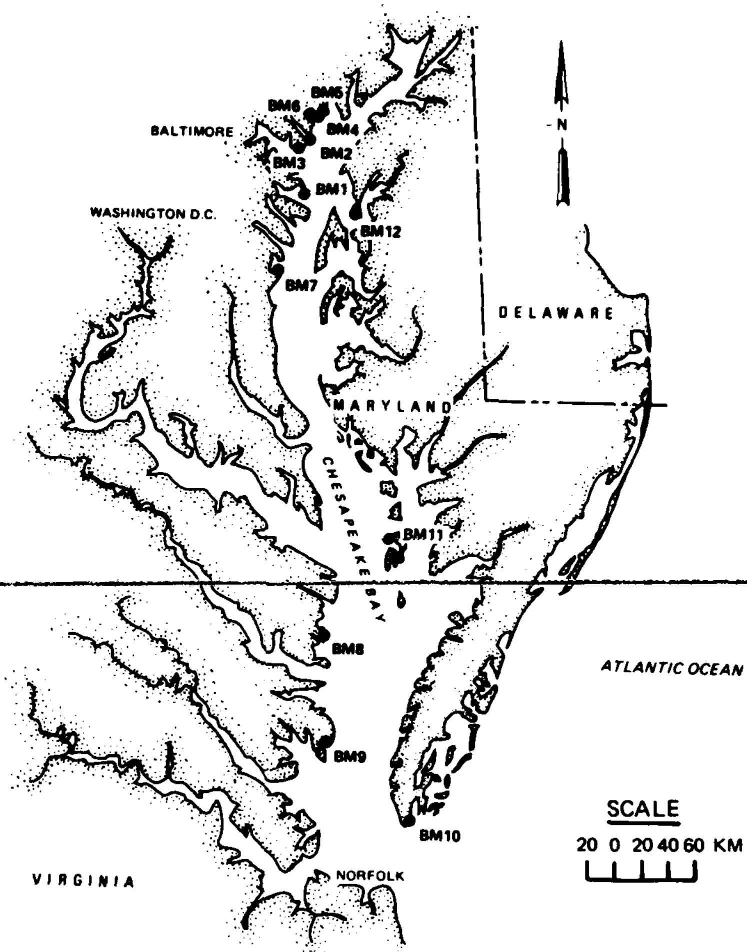

Figure 6. Saltwater natural marsh collection sites, Baltimore, BM1-BM12

BM1-BM6 were located in natural marsh areas near Baltimore Harbor with several near the collection sites of the disposal site study and the sediment collecton sites of the greenhouse study. Collection sites BM7-BM12 were located along the Chesapeake Bay marshes south to the

Norfolk, Va., area near locations of previously sampled disposal sites utilized in the disposal site study and the study by Drifmeyer and Odum (1975).

Cyperus Collection

13. Collections of *Cyperus* species were made from the freshwater marshes associated with the harbors and adjacent coastal areas of Menominee, Mich.; Milwaukee, Wis.; Indiana Harbor, Ind.; Michigan City, Ind.; and Detroit, Mich. (Figure 7). *Cyperus* is not an abundant genus in these freshwater marshes, and, therefore, the sampling system was adjusted. A folding carpenter's ruler was arranged as a 59.2- by 28.7-cm rectangle (1669 cm^2) and placed around each of the four most abundant stands of *Cyperus*. The samples were designated A, B, C, and D. The plants were harvested in the same manner as the *Spartina* with the exception that 3.8-ℓ storage bags were used to contain the plants. A fifth composite grab sample of *Cyperus*, labeled E, was collected by hand picking the plants dispersed around the site.

14. At each collection site an attempt was made to locate any tubers formed by the species present. Tubers were not found.

15. *Cyperus* species (Appendix D) were collected in the U. S. Great Lakes area at 31 sites (Figure 7) during August 1978. Natural marshes were selected near the sediment collection sites, namely Detroit, Menominee, Milwaukee, Indiana Harbor, and Michigan City. Collections in the vicinity of Detroit (coded DE) were made along the west shore of Lake Erie, from Toledo, Ohio, north along the Detroit River to Mt. Clemens, Mich., on 16 and 17 August. Six collections, ME1-ME6, were made in the Lake Michigan shoreline marshes at Menominee, Mich., on 22 August. The emergent lake shore in the Milwaukee (MW) area is not conducive to marsh formation. Only two suitable collection areas were found; plants were collected on 23 August. One natural marsh containing *Cyperus* was found near Indiana Harbor (IN) on 24 August. Thirteen *Cyperus* collections were made along the east shore of Lake Michigan northeast of Michigan City (MC), during 24 and 25 August. Michigan

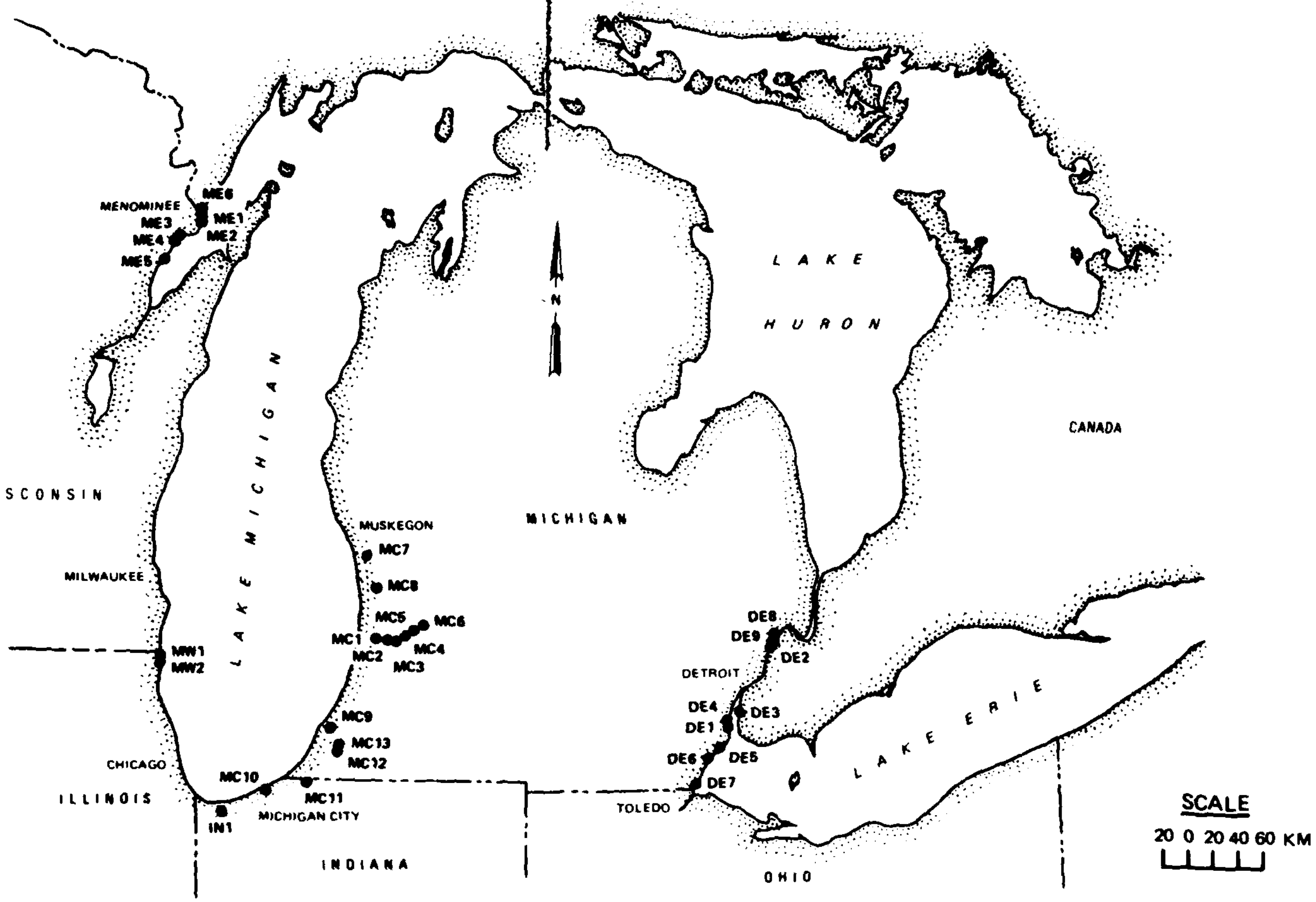

Figure 7. Freshwater natural marsh collection sites; Detroit, DE1-DE9; Menominee, ME1-ME6; Milwaukee, MW1-MW2; Indiana Harbor, IN1; and Michigan City, MC1-MC13

City collections (MC1-MC13) were made along the Kalamazoo River and smaller streams just east of Lake Michigan.

Field Plant Identification

16. *Spartina alterniflora* was identified in the field from vegetative material by comparison with material from the greenhouse study and use of the key to vegetative material in Grey's Manual of Botany (Fernald 1950). No attempt was made to characterize the variety.

17. *Cyperus* is a highly technical genus. The many similar-appearing species may only be accurately distinguished by examination of mature floral parts. Field identifications were made to genus only; species identifications were made later from voucher specimens stored as a permanent record. Representative inflorescences and seeds taken from the plants analyzed were mounted on herbarium sheets and placed in the WES Research Herbarium as sheets numbered 0001FS78 through 0031FS78. The *Cyperus* species collected were identified by utilization of the keys of Voss (1972), Gleason (1952), Fernald (1950), Swink and Wilhelm (1979), Mohlenbrock (1960), and Marcks (1974). Collected specimens were compared with materials in the herbaria of the U. S. National Museum, the Morton Arboretum, and the Department of Botany, Southern Illinois University-Carbondale. Identified as the field collections were *C. esculentus, C. strigosus, C. odoratus (= C. feruginescens), C. erythrorhyzos,* and *C. Englemanni*. The *Cyperus* species are listed by site in Appendix D.

Helicopter Utilization in the Field

18. The availability of helicopters made access to remote areas less time-consuming and allowed site selection to be enhanced by aerial survey. With a helicopter it was possible to select and visit six or more collection sites per day over more than 500 km of coastline. Aerial photographs made of the site, from the helicopter, significantly improved the accuracy of site documentation.

19. The most common helicopter in the size class utilized in this study is the shaft turbine-powered helicopter. The turbine engines have a higher safety factor and use jet fuel A, which contains no lead or compounds that could leave deposits on the plant leaves. When the helicopter was deployed downwind from the collection site, there was little possibility of fuel residue contaminating the plant samples. Additionally, surface contamination was addressed in the treatment of the plant material in the laboratory.

Laboratory Procedures

20. Plant samples were shipped and stored at 4°C until processed. The plant leaf samples were cleaned using the procedure of Elias and Patterson (1975) as modified during the previously described disposal site and greenhouse studies. Several duplicate samples were processed without the cleaning procedure for evaluation of the extent of leaf surface contamination. The plant tissue was oven dried at 70°C, ground into a coarse powder using a Wiley mill, and digested by nitric acid. The plant digestates were analyzed for Zn, Cd, Cu, Ni, Pb, Hg, Cr, Fe, Mn, and As. The instrumentation and detection limits of the chemical parameters are given in Table 1.

Statistical Analysis

21. Descriptive statistics were calculated for all chemical concentration and uptake data for the plants, by species and collectively. A paired test was used for guidance in (a) evaluation of differences in contaminant content of *S. alterniflora* collected from flooded and upland conditions, (b) comparison of contaminant data from washed and unwashed plants addressing the significance of surface contamination, and (c) comparison of quadrat and grab samples of *Cyperus* species.

PART III: RESULTS AND DISCUSSION

Saltwater Natural Marshes

Comparison of flooded and upland plant collections

22. No statistically significant differences in heavy metal content of *S. alterniflora* were found when the means of samples A and B, collected upland at each site, and samples C and D, collected from flooded areas at each site, were compared (Table 2). Studies of rice grown in oxidized and reduced environments suggest that less heavy metal uptake occurs under reduced (flooded) conditions (Bingham et al. 1976; Jugsujinda and Patrick 1977; and Reddy and Patrick 1977). The greenhouse study established the relationship of sediment contamination to plant contaminant uptake for *S. alterniflora* and *D. spicata* under flooded conditions. In addition, *C. esculentus* grown on reduced (flooded) contaminated sediments was shown to take up less Cd, Zn, and Mn than when grown under oxidized (upland) conditions. Comparison of the data of this field study with that of the greenhouse study (Figures 9-17) often shows a generally higher heavy metal concentration in the plants from the natural marsh. The differences between the natural marsh and greenhouse data may be explained by the nature of the tidal fluctuation in the natural saltwater marsh. Generally, during a lunar month the tidal cycles result in flooding of the whole collecting site; additional complete or partial submergence may be due to storm events. Likewise, during the same time span the site may be partially drained and dry or oxidized on the surface. The natural marsh substrate may have been oxidized to a greater extent than the continuously flooded sediment in the greenhouse study. An illustration of tidal range at sites NY1-NY5 (Figure 5) in the Bridgeport, Conn., area was 0 to 2.16 m above mean sea level (msl) for the collection date of 8 August 1978, but the range for the year, excluding storm events, was -0.46 to 2.41 m above msl (U. S. Department of Commerce 1977). As a consequence, the marsh sediment has an opportunity to drain and become oxidized when the tide is -0.46 m above msl. Increased

oxidation of the marsh substrate may increase plant available heavy metals with a resultant increase in plant contents.

Comparison of the heavy metal content of washed and unwashed samples

23. Statistically significant differences in heavy metal concentrations were only found between Cd concentrations of washed and unwashed *S. alterniflora* when leaf samples were compared (Table 3). These data are in contrast to the significantly higher leaf adsorbed Ni and Zn of the disposal site survey attributed to airborne contaminants. Apparently the natural marsh plants collected were not noticeably influenced by airborne contaminants. It appears, from the sporatic results of washing, that washing the leaves is only necessary when airborne contamination is a reality at the collection site.

Heavy metal content of *S. alterniflora* leaf tissue

24. Leaf tissue heavy metal concentrations (Appendix E) were compared with those determined in the previously described greenhouse and disposal site studies and with existing literature values.

25. Both leaf tissue concentration (Appendix E) and total plant uptake values, calculated by multiplying leaf tissue concentration by the total yield of the sample collected and then dividing by the area sampled (square metres) (Appendix F), were considered for each metal.

26. The data presented in Appendices E and F indicate that a pronounced geographic variation occurs in the baseline heavy metal levels in the natural marsh. To address this variation, site-specific comparisons were made utilizing existing literature values and portions of the data collected during the disposal site study. Leaf tissue concentration and uptake data from natural marsh and disposal sites were compared for sites located within approximately 0.5 deg of latitude and longitude (Table 4). These are arbitrarily designated areas in which the compared sites are no more than 60 km apart within an area of approximately 11,840 km^2. Each area is small enough to allow regional grouping of data loci for comparison. These resultant areas were designated areas A through L (Figure 8).

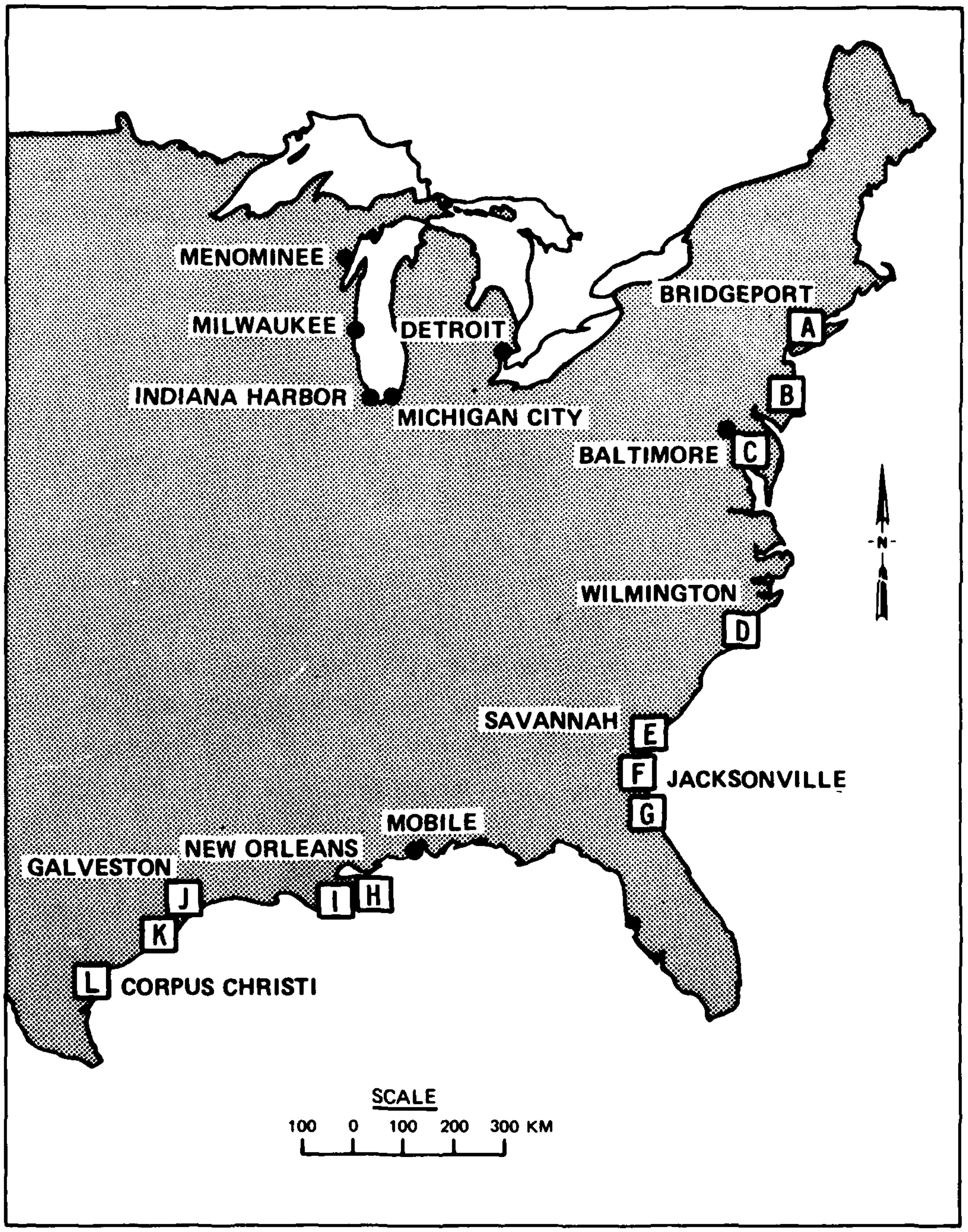

Figure 8. Sites A through L for site-specific comparisons of leaf tissue concentrations and uptake data from natural marsh and disposal areas

27. The comparison of total heavy metal uptake values of plants from natural marsh and disposal site at maximum vegetative growth is intended to reflect the generally greater biomass found on the disposal sites (Table 5) and the concomitant increased potential for contaminant movement into the biota. The comparisons of disposal site uptake, based on collections made in 1975 and the natural marsh survey of 1978, may be less indicative of real differences than comparisons of plants collected during the same year.

28. Arsenic. The concentration of As in *S. alterniflora* was generally very low, usually less than 0.03 $\mu g\ g^{-1}$ or below detection limits (Figure 9). This is similar to the level observed in the greenhouse study. Due to the hot acid digestion of the plant samples, these values may be low due to As loss via volitization. In the natural marsh a few relatively high levels were observed at JV9 C, 0.83 $\mu g\ g^{-1}$, and JV1 C, 0.48 ug g^{-1}. Arsenic uptake for JV1 through JV4, which are in Areas E, F, and G in Figure 8, ranged from 25.5 to 63.7 $\mu g\ m^{-2}$. Jacksonville 9 was the location with the greatest plant uptake value, 164.6 $\mu g\ m^{-2}$, without explanation. Other areas with high total plant As uptake values were NY2, NY3, and NY4 in Area A, Long Island Sound; BM1, near Baltimore Harbor; CC10 and CC11 in Area K; CC1, Nueces Bay in Area L; and NO11 and NO12 in Area I. There are no disposal site data available with which to make a total As uptake comparison.

29. Cadmium. The Cd content of *S. alterniflora* leaves was usually less than 0.02 $\mu g\ g^{-1}$, a level slightly less than that of the disposal site study and significantly less than the levels of the greenhouse study (Figure 10). A few samples from NY1, NY3, and NY4 (Figure 5) ranged in concentration upward to 0.72 $\mu g\ g^{-1}$, although these sites were not uniformly high in Cd. The uptake in the natural marsh in Area A, an industrial area of long standing that includes these sites, was notably higher than that of the disposal site of the same area (Figure 11). In the remaining coastal areas, the Cd uptake values were lower in the natural marshes sampled or equal to those of the disposal sites (Figure 11). Dunstan and Windom (1975) found an average concentration of 0.61 $\mu g\ g^{-1}$ Cd in the natural marshes along six southeastern United States river

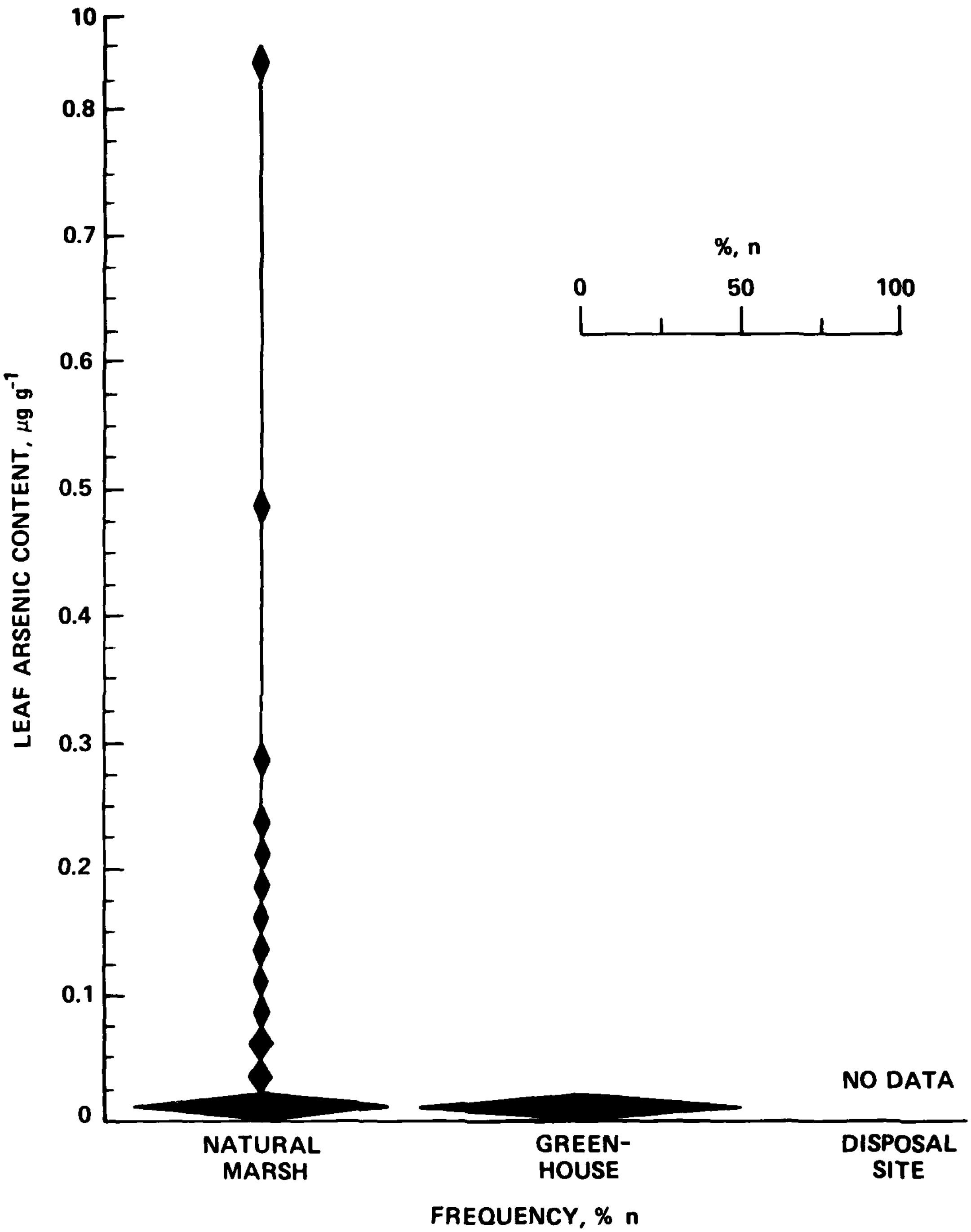

Figure 9. Distribution of arsenic concentration, *S. alterniflora*

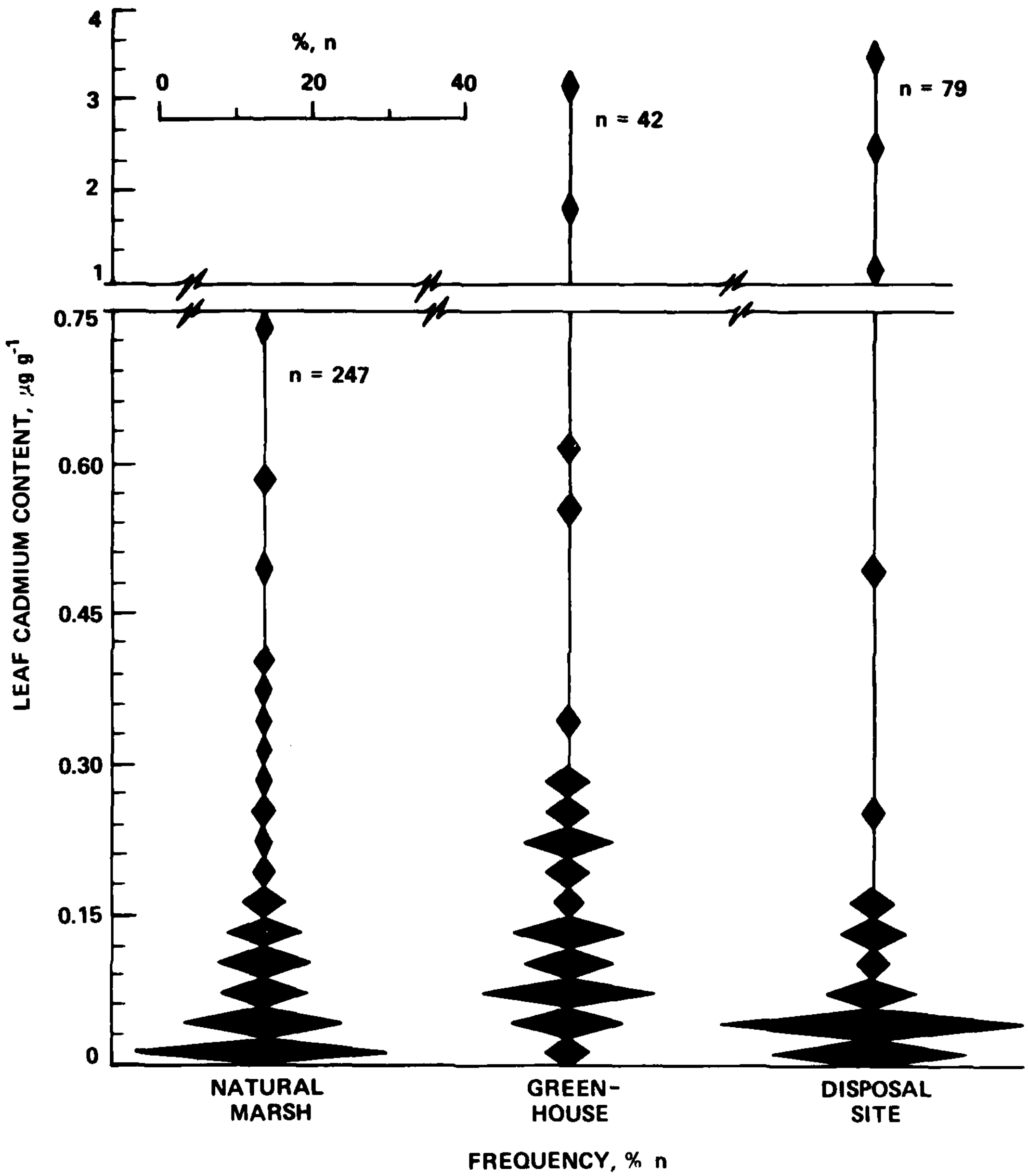

Figure 10. Distribution of cadmium concentrations, *S. alterniflora*

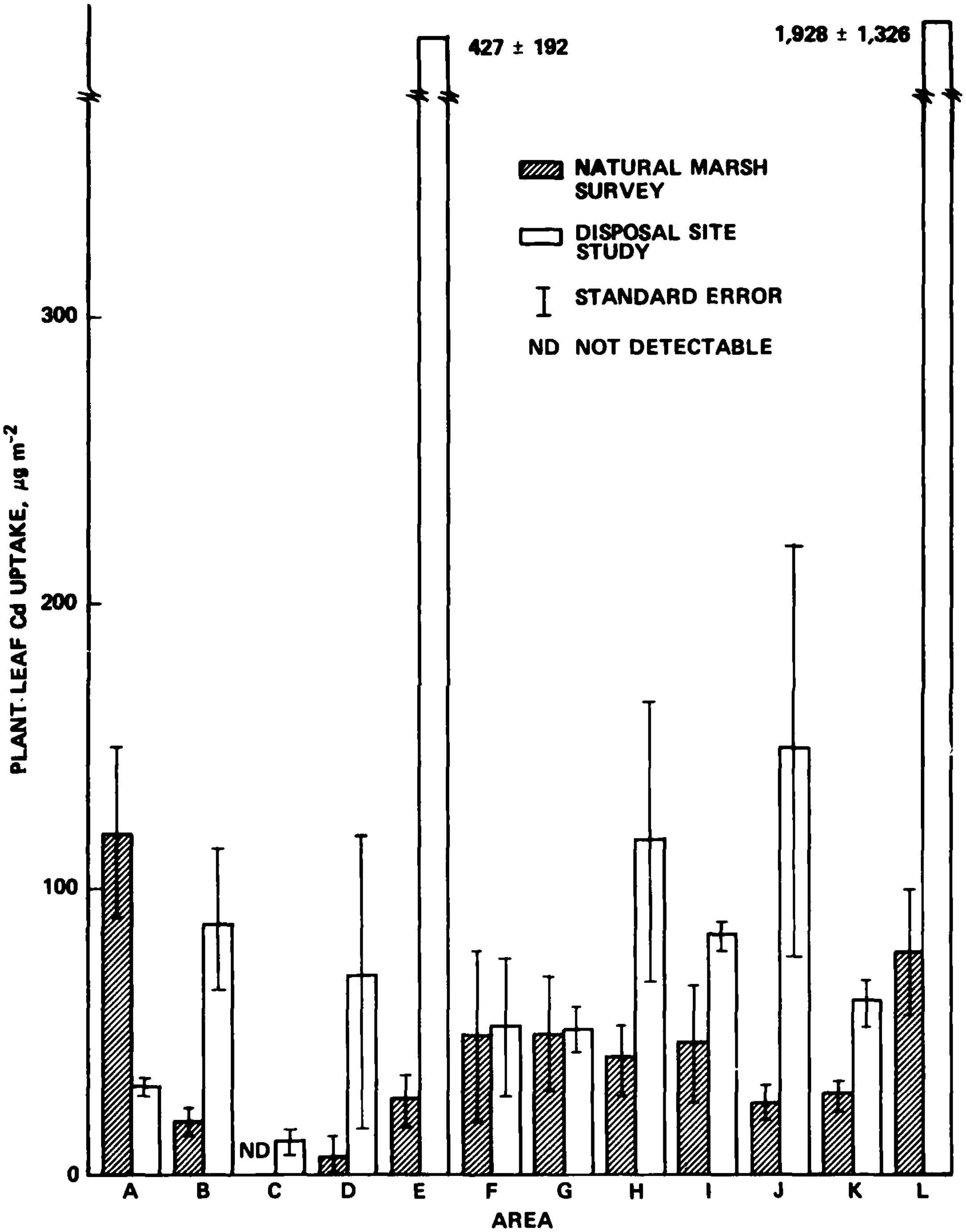

Figure 11. Total cadmium uptake by *S. alterniflora* in natural marshes and disposal sites

systems, a value higher than the mean of 0.02 μg g^{-1} for the Cd in the same species reported in this study. The plant Cd mean of the JV sites that generally corresponds with Dunstan and Windom's (1975) collection area was 0.07 μg g^{-1}. With the exception of Area A (Figure 8), Cd content and uptake in natural marsh *S. alterniflora* was less than or equivalent to that of the same species grown on disposal sites or flooded contaminated sediments (Figure 11). Disposal sites appear to be contributing more Cd into the environment via plants than the natural marsh.

30. Chromium. The mean Cr content of natural marsh *S. alterniflora* was 1.17 μg g^{-1} (Figure 12). This is a significantly higher level than found in either the greenhouse or the disposal site studies. The levels of Cr uptake in the natural marsh of the comparison areas (Figure 13) were higher or within one standard error of the uptake of the disposal sites. Area D (Figure 8) would perhaps be expected to have a higher level due to the Wilmington, N. C., fabric mills and the utilization of Cr in dyes, but this difference was not statistically significant. There are no data available in the literature for further comparison.

31. Copper. Leaf samples of *S. alterniflora* grown in natural marshes contained 1.2 to 5.5 μg g^{-1} Cu. This is similar to the Cu content of those plants from the disposal site and greenhouse studies (Figure 14). Broome, Woodhouse, and Seneca (1973) reported 2.0 to 4.0 μg g^{-1} Cu from *S. alterniflora* collected from natural marshes along the North Carolina coast. Collections made from the same general area, JV11 and JV12 (Figure 4) during this field survey yielded values of 0.2 to 3.0 μg g^{-1}, values similar to those of the previous authors. Analysis of *S. alterniflora* from the U. S. gulf coast by Gosselink, Hopkinson, and Parrondo (1977) indicated a mean Cu level of 4.0 μg g^{-1}. The analyses field survey collection in the New Orleans (NO) area indicated the leaf samples contained 0.2 to 11.2 μg g^{-1} Cu (Appendix E6) with the majority of the samples falling in the 2.0- to 4.0-μg g^{-1} range. These Cu content levels were similar to those found in *S. patens* and *D. spicata* during the disposal site study. The highest concentrations observed were in Areas A and B (Figure 8) and NO4 and NO5 (Figure 3). The former locations (Areas A and B) were associated with intensive

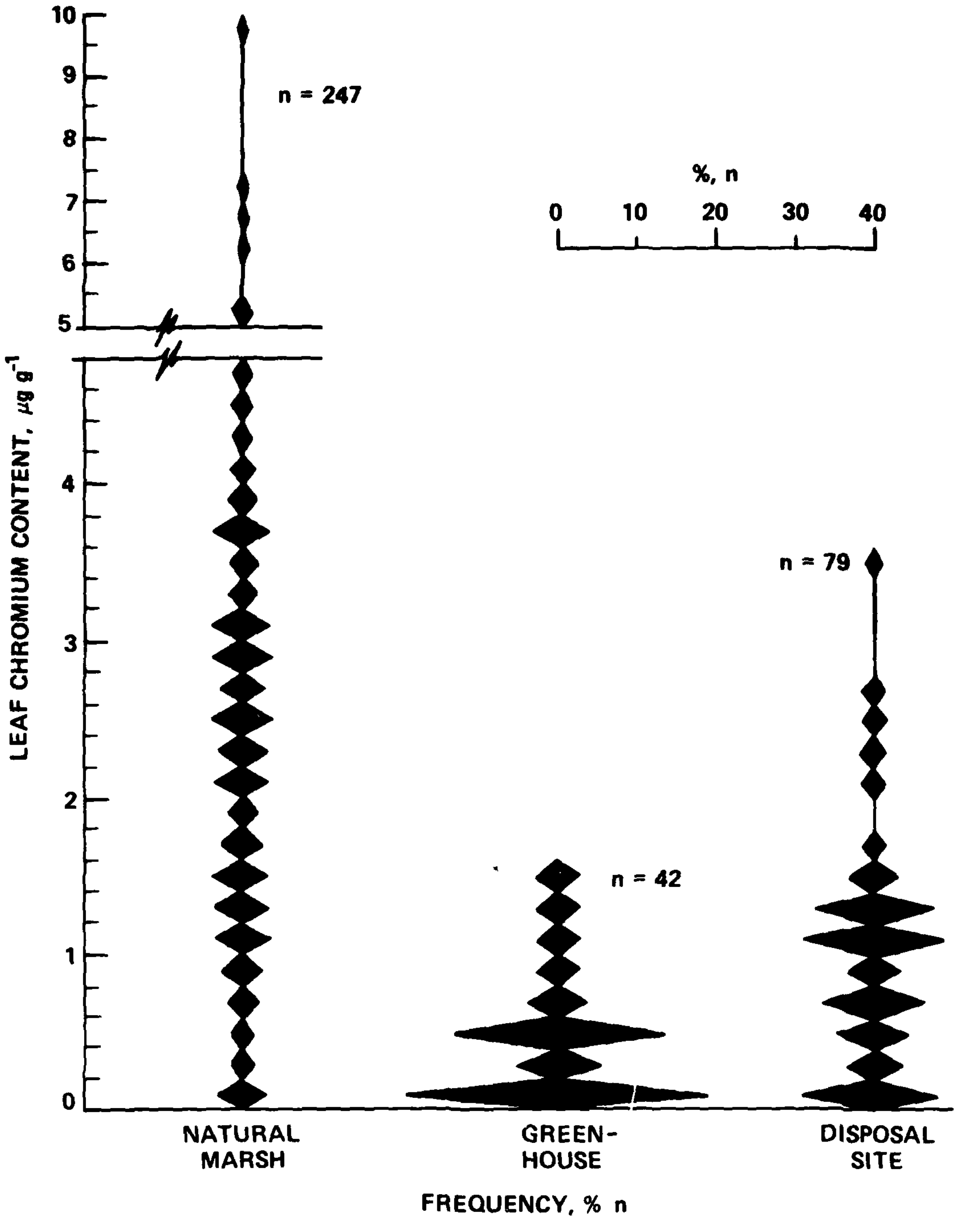

Figure 12. Distribution of chromium concentrations, *S. alterniflora*

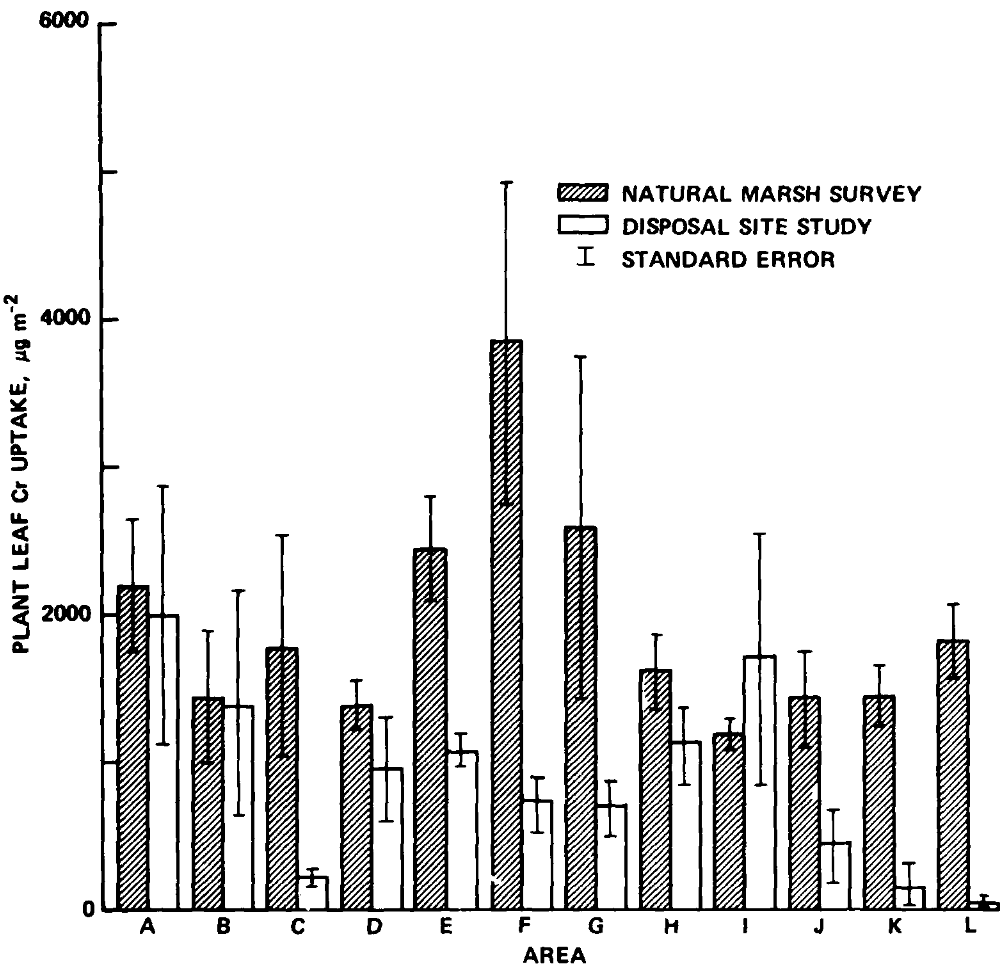

Figure 13. Total chromium uptake by *S. alterniflora* in natural marshes and disposal sites

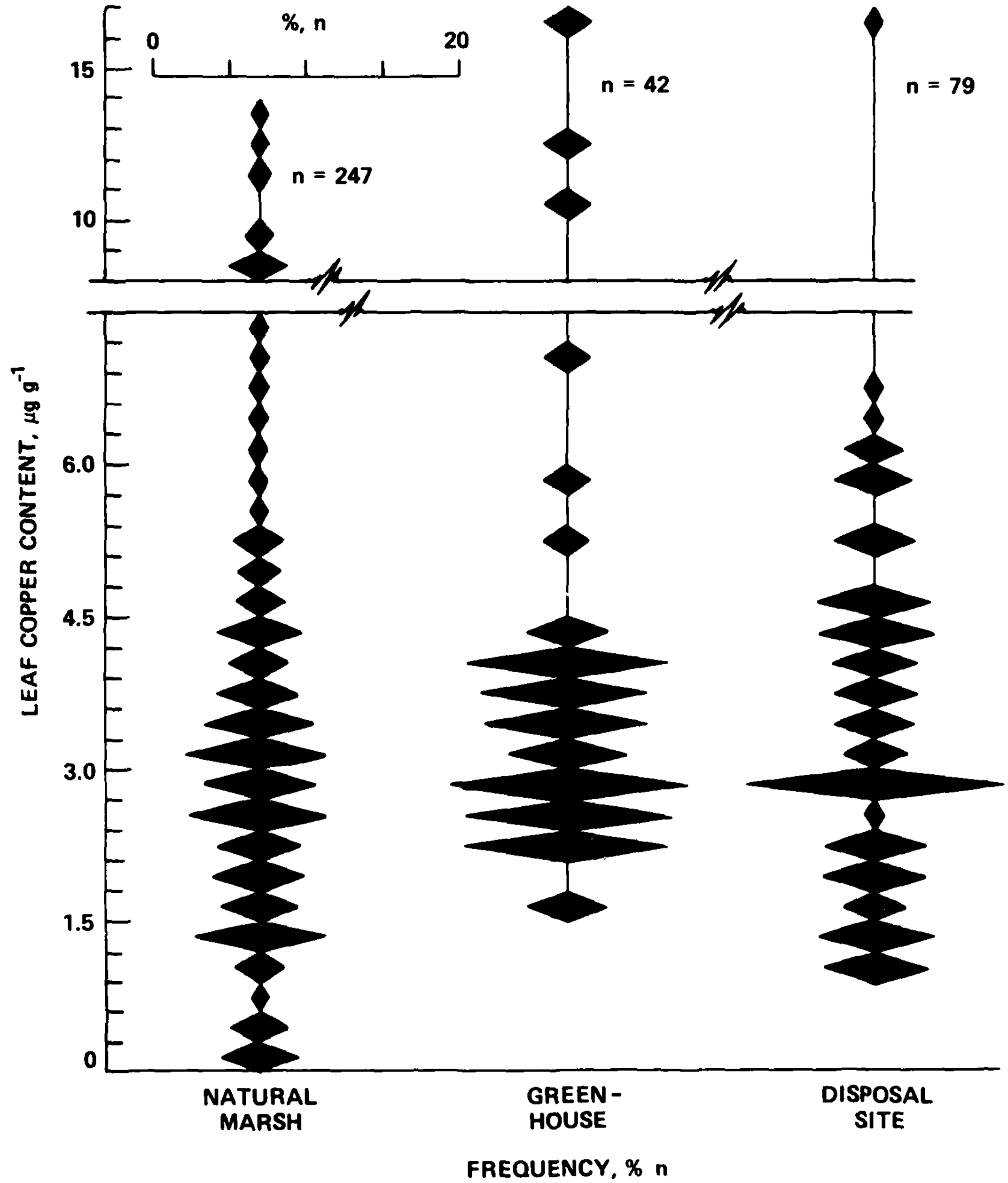

Figure 14. Distribution of copper concentrations, *S. alterniflora*

industrialization, but the latter (NO4 and NO5) were located in isolated marsh areas. In terms of leaf content data, it appears that plants grown on flooded contaminated sediment and plants grown on dredged material disposal sites did not contain any more Cu than natural marsh plants.

32. Total uptake of Cu in the natural marsh plants was generally less than or equal to that of the plants collected during the disposal site study (Figure 15). This observation reflects the generally lower biomass production in the natural marsh as compared to that in the disposal site. As expected from the previous discussion, natural marsh Cu uptake was greatest in Area A. In Area C, the natural marsh Cu uptake was considerably higher than that of the disposal sites. This is mainly the result of a higher biomass production in the natural marsh in that area.

33. Iron. The concentration of Fe in natural marsh *S. alterniflora* was marginally greater than that recorded in the greenhouse study (Figure 16). This was contrary to the more completely reduced conditions maintained in the greenhouse study under which Fe availability was thought to be increased. Consistently high values for Fe were associated with more than one sample at JV9, NY1, NY4, NY6, and NO12. NY1, NY4, and NY6 were sites located in and around Bridgeport, Conn., an area of long standing industrial activity (Figure 5). In addition, NY6 was adjacent to a gun club on Stratford Point, Conn., which is also a site with high plant leaf Pb content. The Fe uptake at these sites is also high, ranging from 287,482 to 792,682 $\mu g\ m^{-2}$. Site JV9 was located at Santee Point, S. C., and appeared to be essentially free from any source of contamination (Figure 4), although the Fe concentration ranged from 80 to 4738 $\mu g\ g^{-1}$, with a mean of 1328 $\mu g\ g^{-1}$. Dunstan and Windom (1975) found 1000 $\mu g\ g^{-1}$ Fe in *Spartina*, leaves and rhizomes combined, at this same location. Site NO12 samples were collected on Marsh Island, a Louisiana State Wildlife Refuge (Figure 3). There were no Fe data collected during the disposal site study for comparison.

34. Lead. The mean Pb concentration of natural marsh *S. alterniflora* was 1.3 $\mu g\ g^{-1}$, a value greater than that of the greenhouse study, 0.6 $\mu g\ g^{-1}$, and the disposal site study, 0.9 $\mu g\ g^{-1}$ (Figure 17). Plant

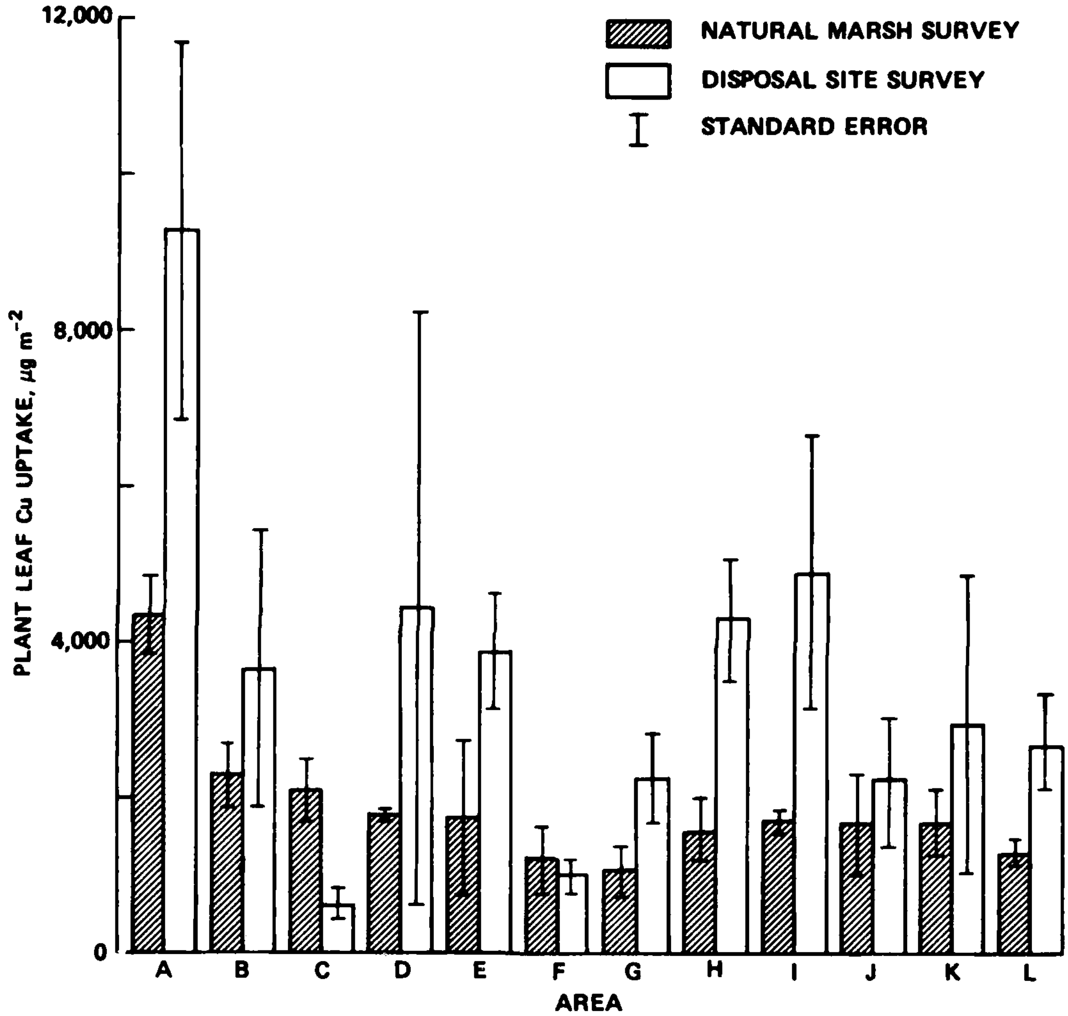

Figure 15. Total copper uptake by *S. alterniflora* in natural marshes and disposal sites

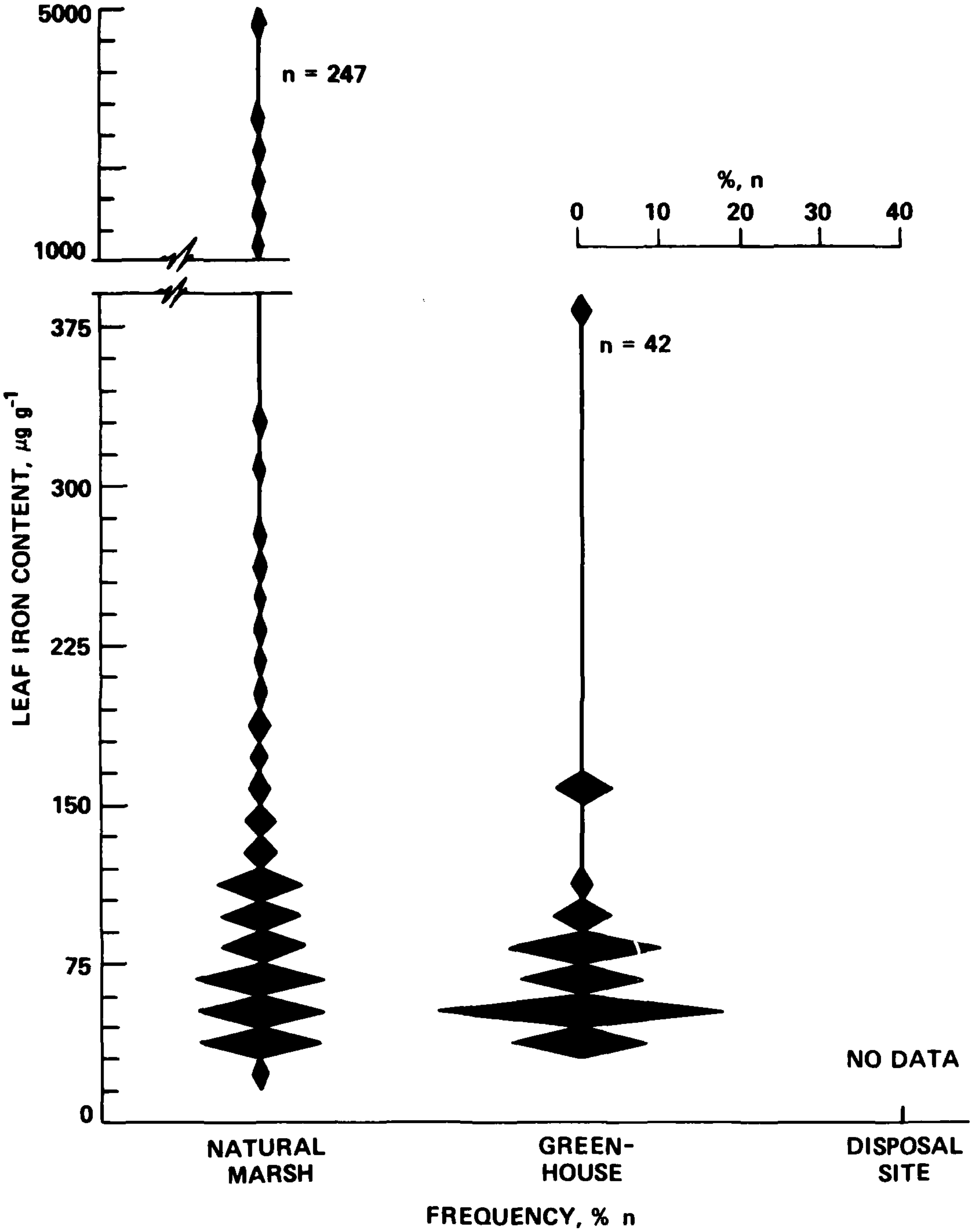

Figure 16. Distribution of iron concentrations, *S. alterniflora*

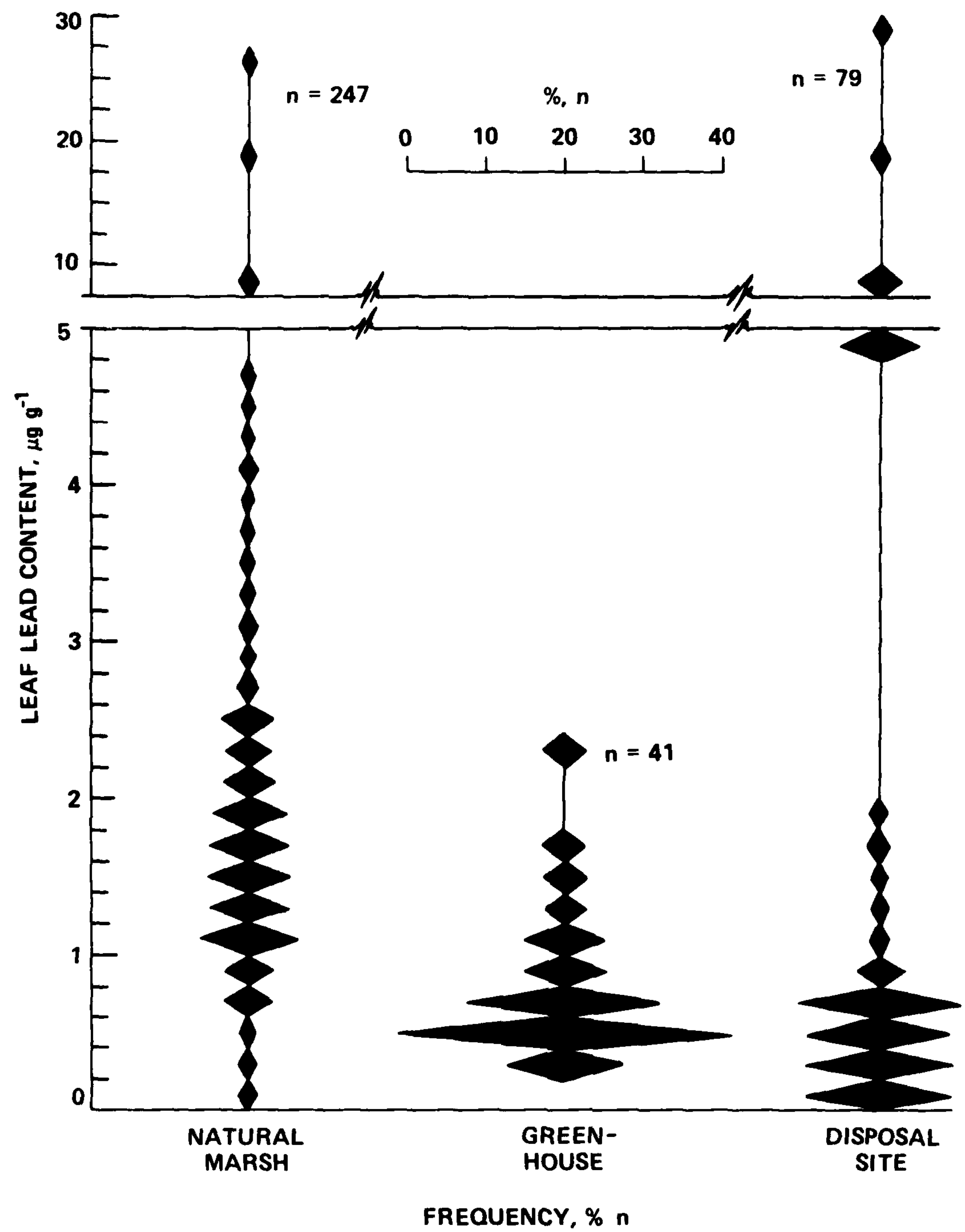

Figure 17. Distribution of lead concentrations, *S. alterniflora*

leaf Pb content was greater than 5.0 μg g^{-1} at only one site, NY6. This natural marsh was adjacent to the gun club on Stratford Point, where the high Pb content may be due to Pb shotgun pellets. This site was also high in Fe. Drifmeyer and Odum (1975) reported a concentration of 9.1 μg g^{-1} Pb in *S. alterniflora* collected from a confined dredged material disposal area in Virginia and 1.9 μg g^{-1} in a natural marsh nearby. The mean of Pb concentrations in *S. alterniflora* in the natural marsh plants sampled during this study, 1.3 μg g^{-1}, is slightly lower than the value of the previous authors but represents a range of 0.0 to 26.7 μg g^{-1} (Appendix E). The mean of the Pb concentrations from sites BM8 to BM11 (Figure 6), near the collection area of Drifmeyer and Odum (1975), was 1.8 μg g^{-1}. Lead uptake was found to be highest in Area A that includes NY6 (Figure 18). With the exception of Areas A, B, and L, Pb uptake in the natural marsh was less than or equal that in the disposal sites. Disposal site uptake levels were higher than 1000 μg m^{-2} only in Areas A, B, and L.

35. Manganese. Levels of Mn in the natural marsh were found to be significantly lower, with a mean of 51.6 μg g^{-1}, than those of the greenhouse study (Figure 19). No data from the disposal site study were available for comparison. As demonstrated in the greenhouse study with *Cyperus esculentus*, Mn uptake would be greater under reduced conditions. As tidal fluctuations may allow some oxidation, the actual difference between the greenhouse and natural marsh plant leaf Mn is more pronounced. In contrast to the greenhouse study, examination of the Fe-Mn ratio did not indicate that Mn levels were generally higher than those of Fe. Manganese concentrations were uniformly high in Areas C, H, and J (Figure 8) and also in the NO6 area (Figure 3). Total plant Mn uptake (Appendix F) was commensurately higher in these areas also. There appeared to be no relationship between Fe and Mn concentration data on visual comparison.

36. Mercury. The concentration of Hg in *S. alterniflora* leaves was relatively low and similar to the disposal site findings, approximately one third the level found in the greenhouse plants (Figure 20). There were no areas of uniformly high Hg concentrations. While Dunstan and Windom (1975) found up to 0.44 μg g^{-1} of Hg in *S. alterniflora* in the

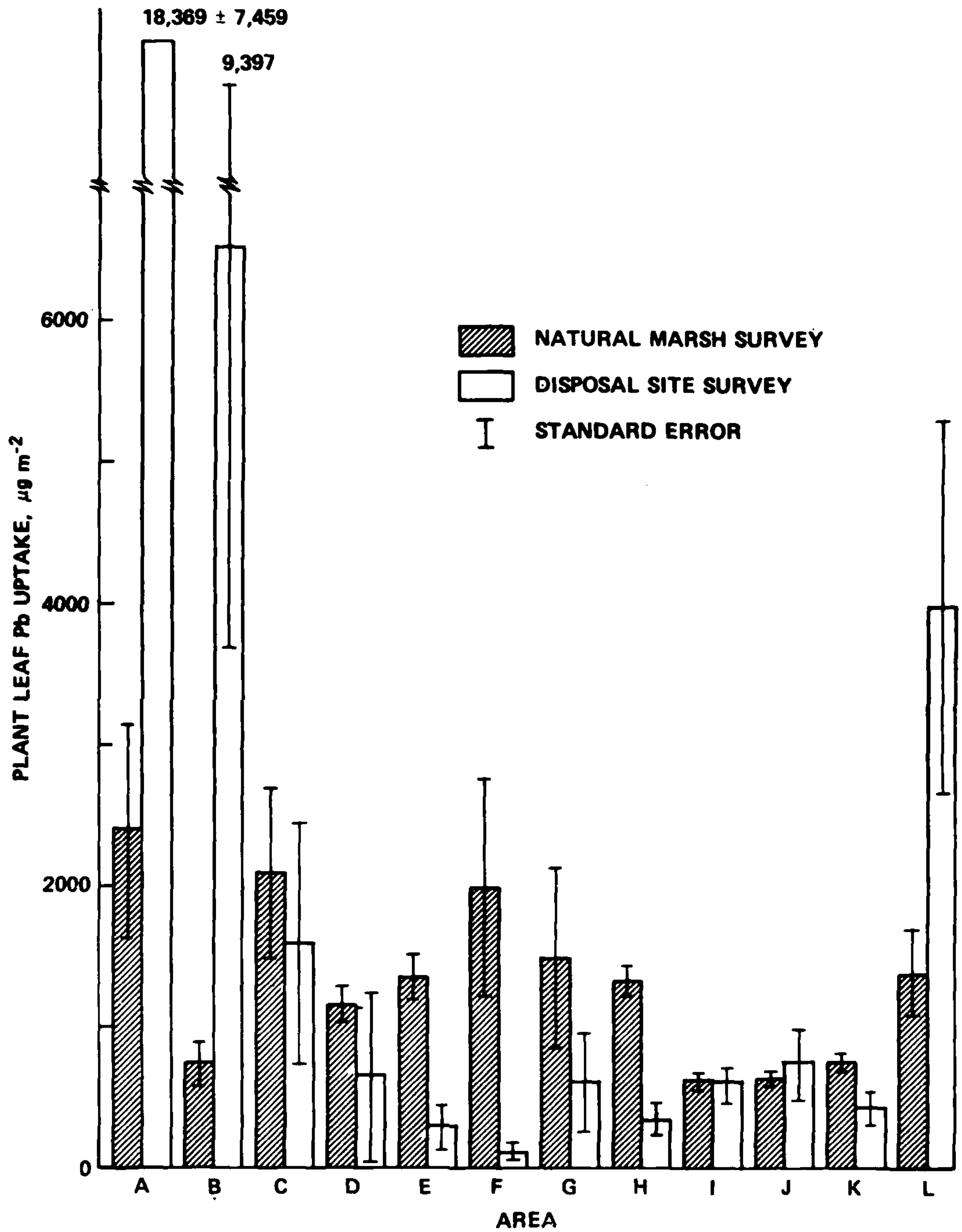

Figure 18. Total lead uptake by *S. alterniflora* in natural marshes and disposal sites

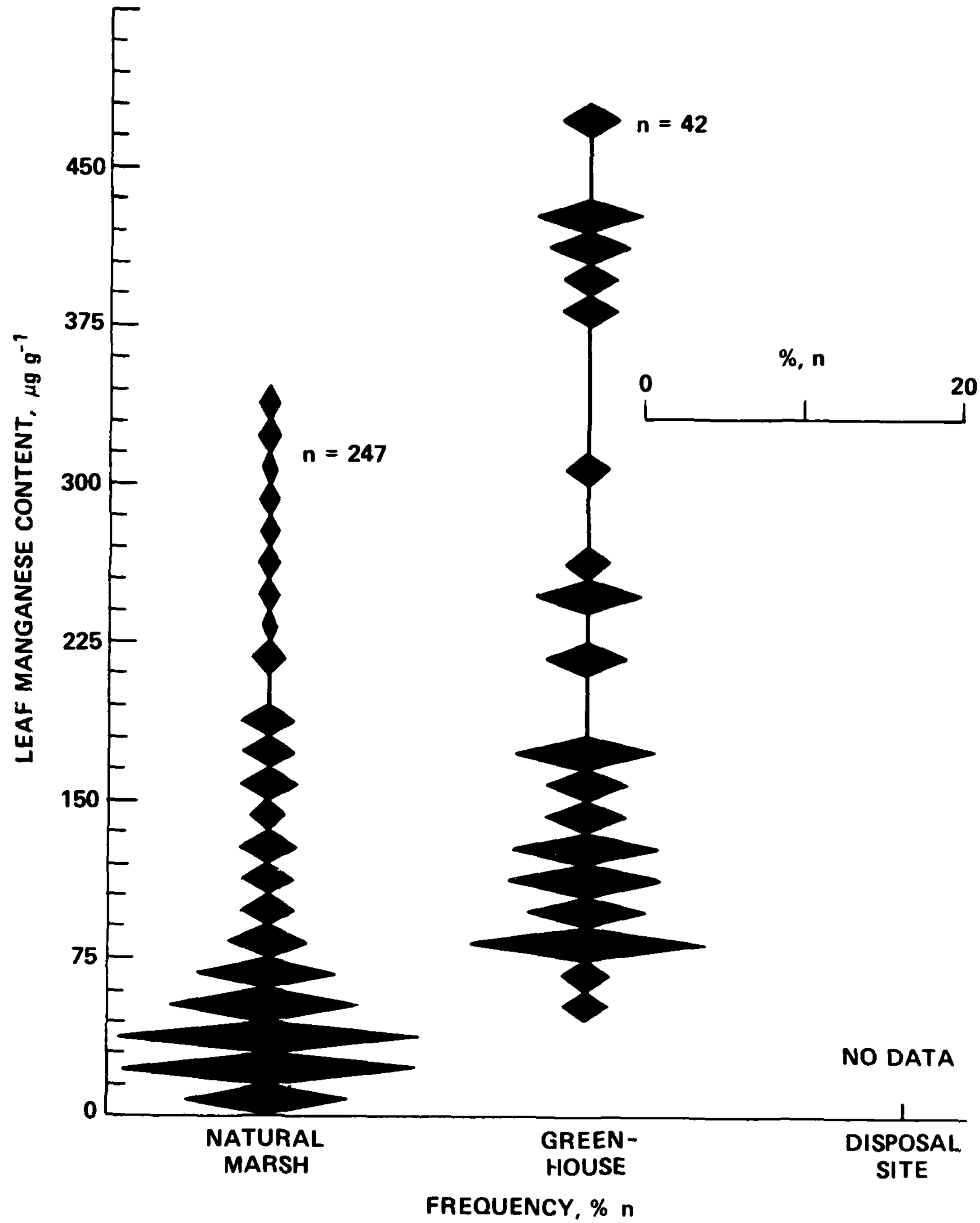

Figure 19. Distribution of manganese concentrations, *S. alterniflora*

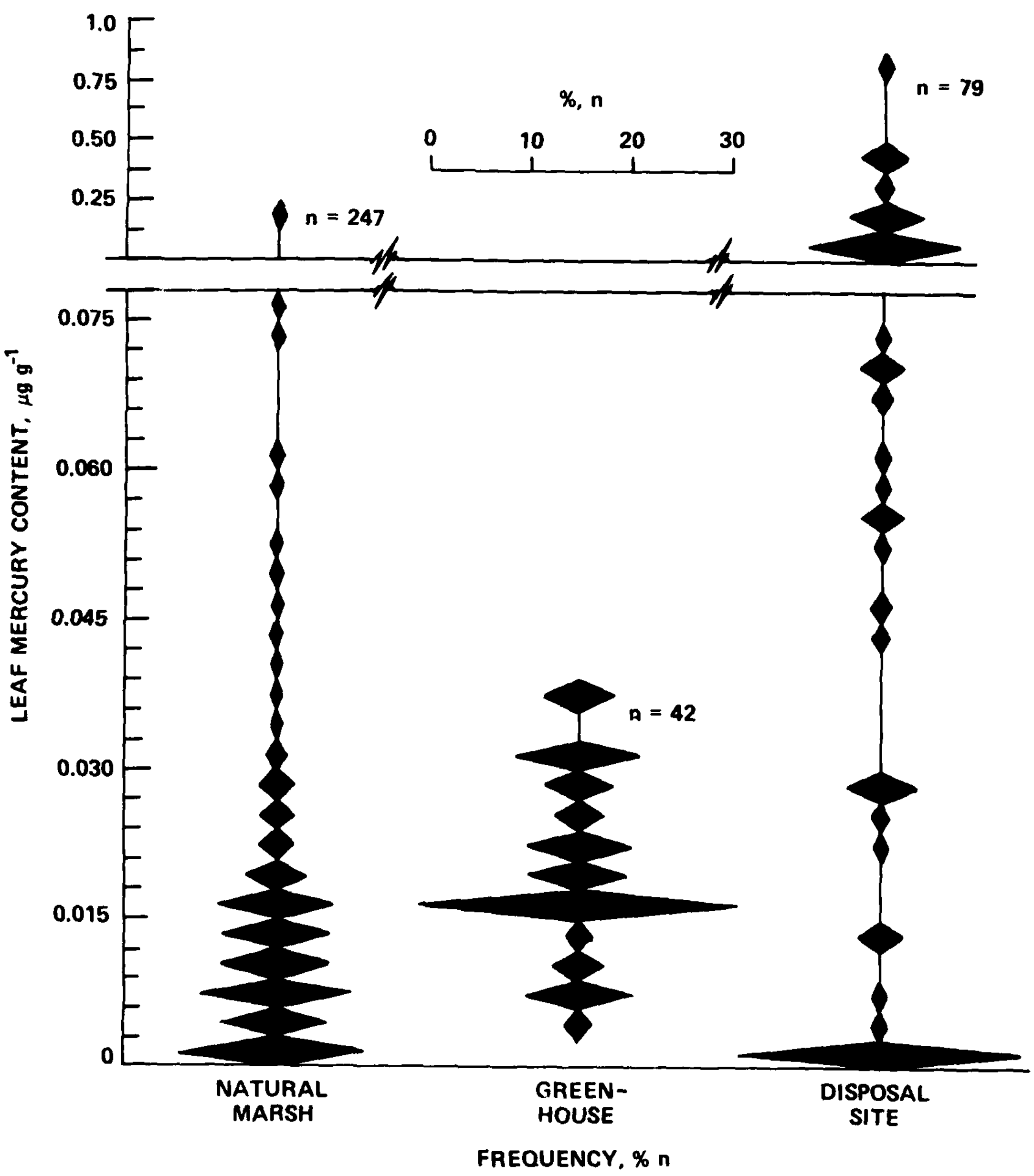

Figure 20. Distribution of mercury concentrations, *S. alterniflora*

area referred to here as JV, no concentration of Hg determined during the natural marsh survey exceeded 0.07 μg g^{-1}. The levels of Hg in saltwater natural marsh plants approximate those found in plants grown on dredged material. Due to the low levels of Hg in both natural marsh and disposal site plants, extensive variation appears in the uptake comparison (Figure 21). Natural marsh Hg uptake values never exceeded 43 μg m^{-2} (Appendix F). These low values may be a result of Hg loss through volitization during the hot acid digestion of the plant material.

37. Nickel. The Ni concentration of *S. alterniflora* leaf tissue was generally less than 6.0 μg g^{-1} (Figure 22). The distribution of leaf Ni concentrations generally paralleled that of the disposal site data in contrast to the very low levels, 0.3 μg g^{-1}, found in the greenhouse study. Nickel uptake in the natural marsh plants (Figure 23) varied from higher (Areas E, F, K, and L) to within one standard error of the disposal site plants. Area A showed less Ni uptake in natural marsh plants than disposal site plants (Figure 23). The concentration of Ni at Areas E and F were, however, less than 3.5 μg g^{-1} Ni, but due to more biomass production in the natural marsh compared to the disposal site, these areas showed the highest uptake values.

38. Zinc. The mean concentration of Zn in natural marsh *S. alterniflora* was 15 μg g^{-1} (Figure 24). This value is slightly lower than those from the disposal site study and significantly lower than the 43 μg g^{-1} mean of the greenhouse study plants. Gosselink, Hopkinson, and Parrondo (1977) found 11 μg g^{-1} Zn in *S. alterniflora* of natural marshes in Louisiana. Collections from the same general vicinity, NO (Figure 3), yielded a higher mean of 14 μg g^{-1}. *Spartina alterniflora* collections from JV11 and JV12 (Figure 4), near the locations from which Broome, Woodhouse, and Seneca (1973) reported 17 μg g^{-1} Zn, contained a mean of 23 μg g^{-1}. These values are higher than the 7 to 10 μg g^{-1} Zn reported by Williams and Murdock (1969) from studies made further north at Beaufort, N. C. In the vicinity of BM8 to BM11 (Figure 6), in Virginia, Drifmeyer, and Odum (1975) reported Zn concentrations of 39 and 20 μg g^{-1}, respectively, from a dredged material disposal area and an adjacent natural marsh. In comparison, the concentration of Zn

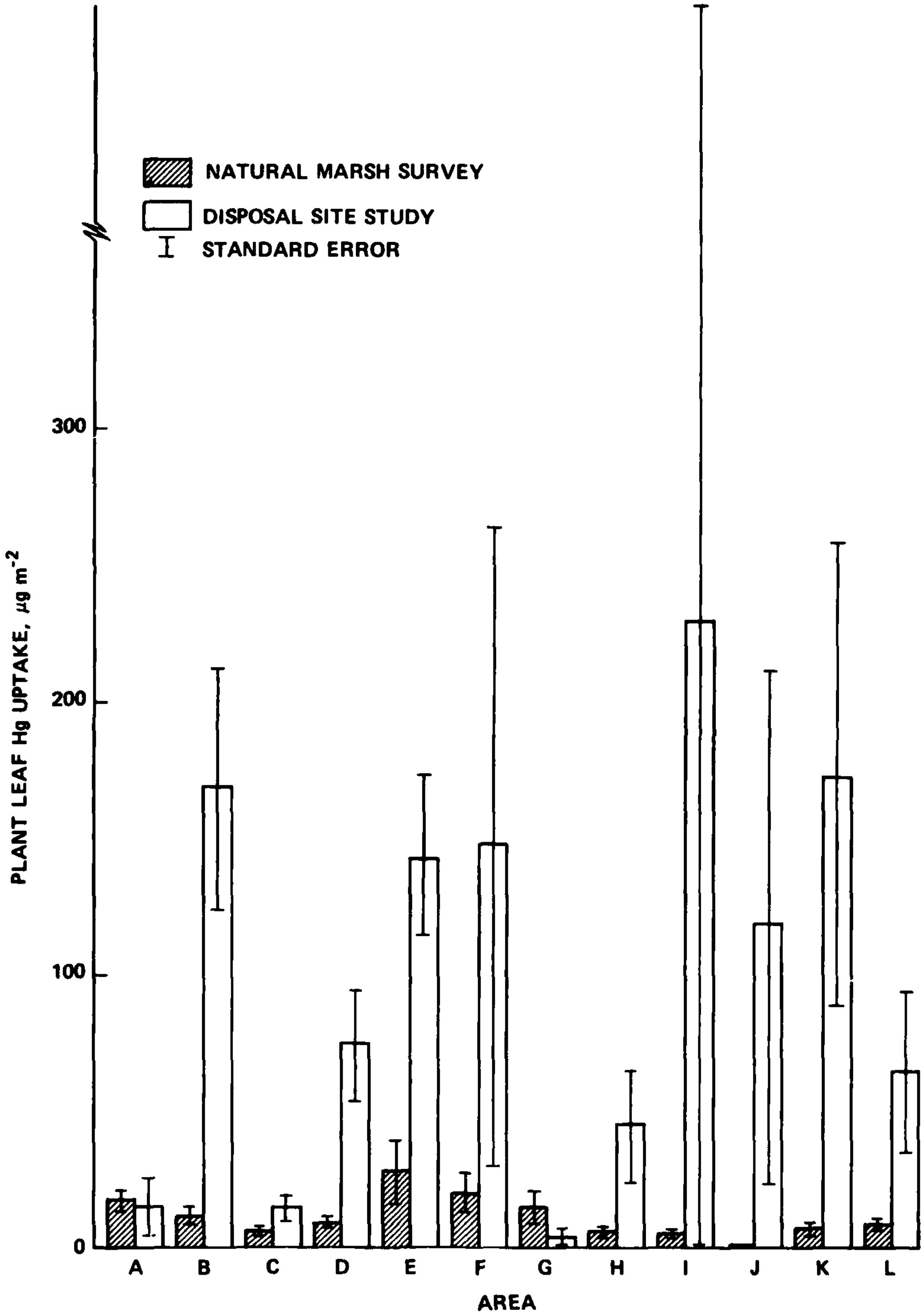

Figure 21. Total mercury uptake by *S. alterniflora* in natural marshes and disposal sites

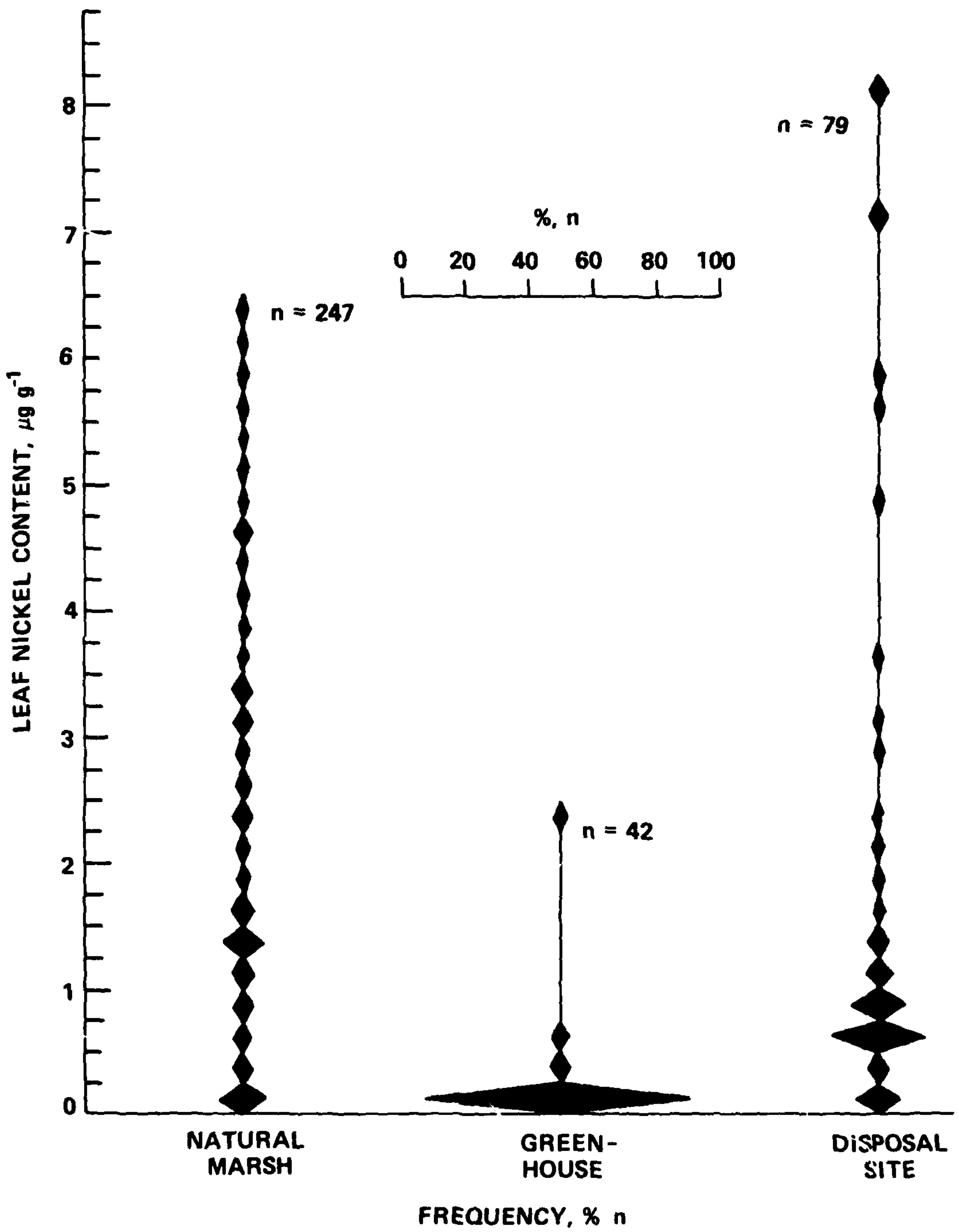

Figure 22. Distribution of nickel concentrations, *S. alterniflora*

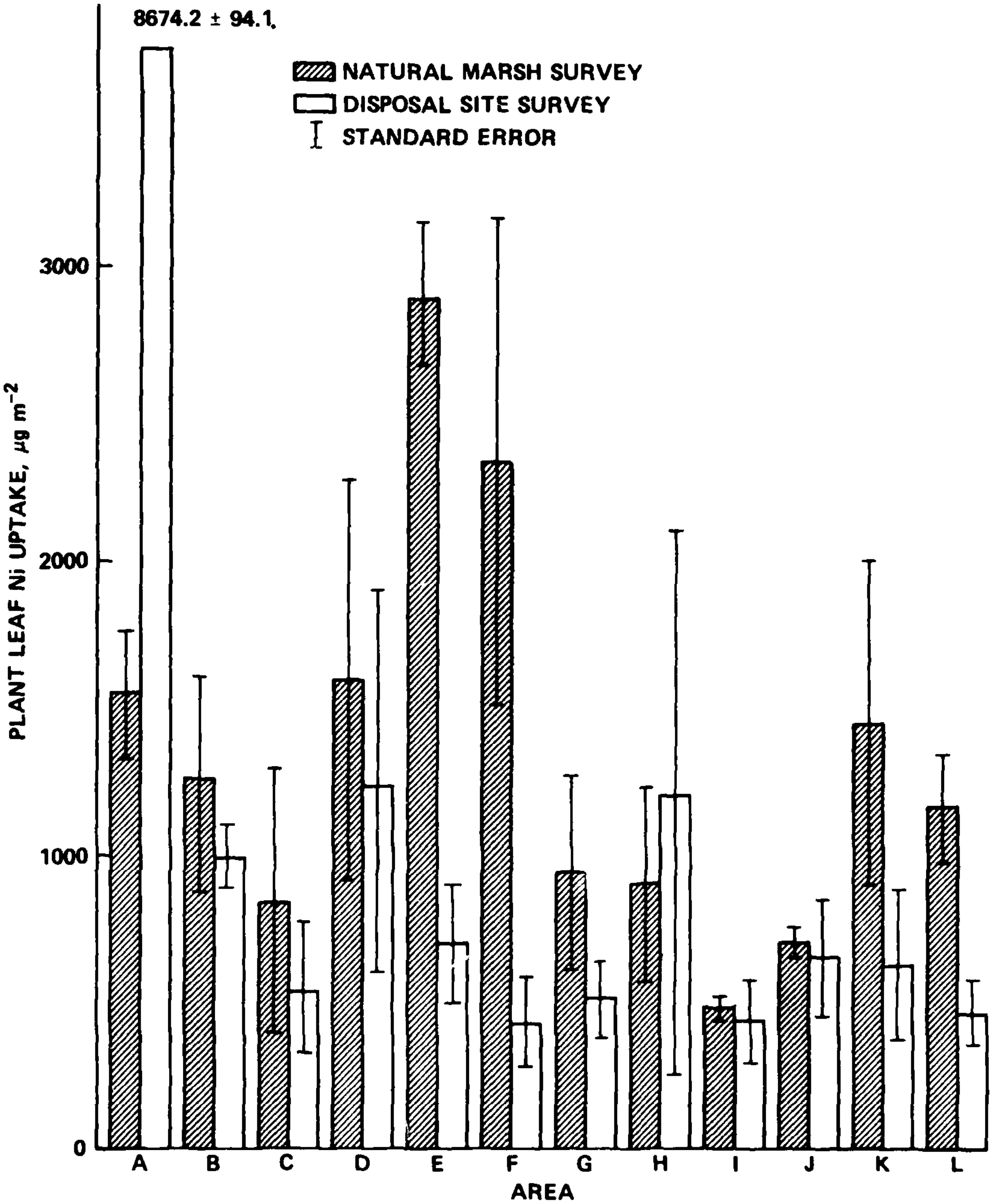

Figure 23. Total nickel uptake by *S. alterniflora* in natural marshes and disposal sites

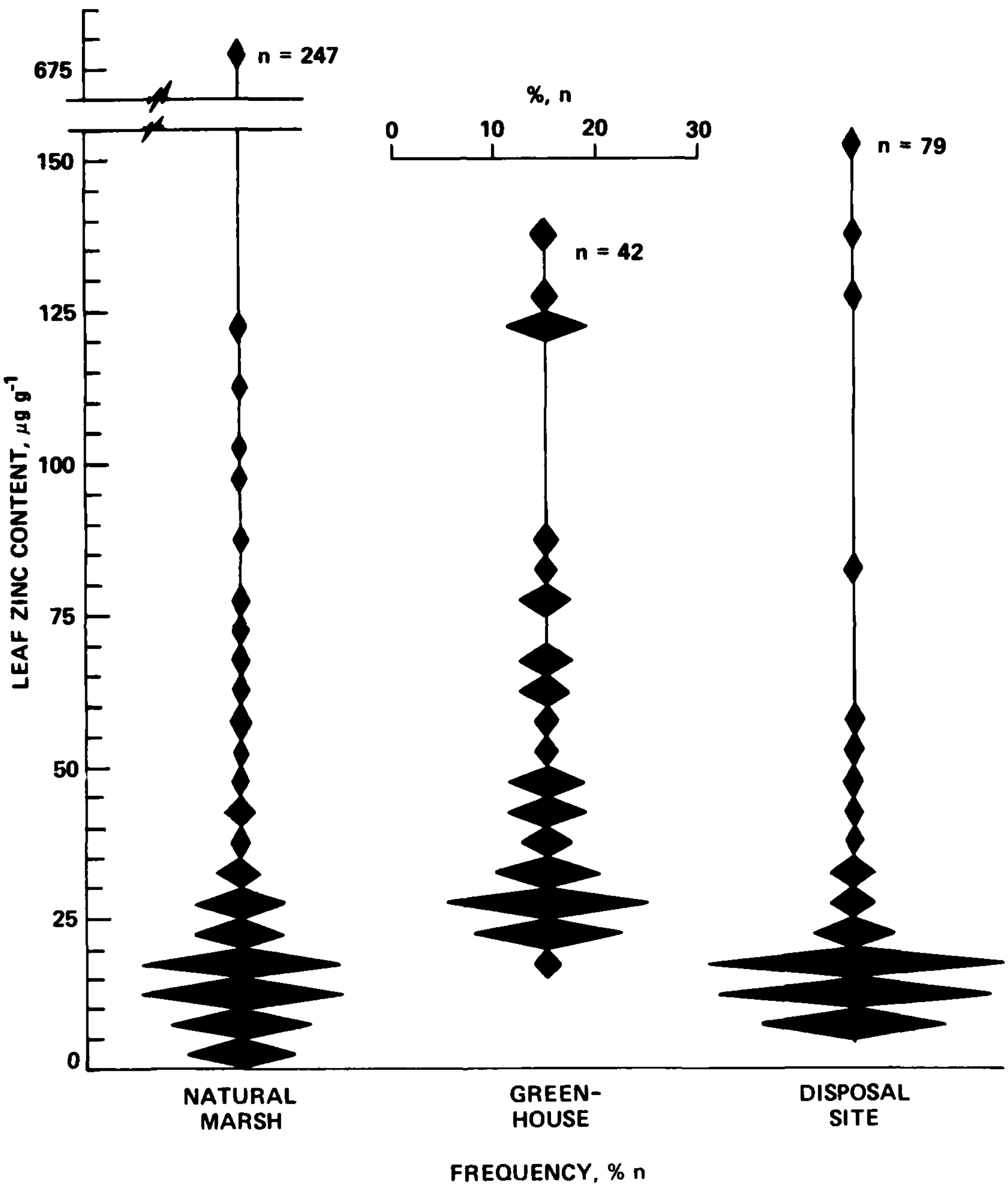

Figure 24. Distribution of zinc concentrations, *S. alterniflora*

found at BM8 to BM11 was 15.81 μg g^{-1}. Zinc concentrations were not uniformly greater than 45 μg g^{-1} in Area L (Figure 8) where, until 1975, a Zn smelter had been in operation. Zinc uptake in the natural marsh was generally equivalent to that of the disposal sites (Figure 25). Notable exceptions were the disposal sites in Area L which yielded plants with much higher Zn uptake than the natural marsh. Higher biomass production on the disposal site may have accentuated this difference in Zn uptake.

Freshwater Natural Marshes

Comparison of heavy metal contents of quadrat and grab samples of *Cyperus*

39. Statistical comparisons of the means of heavy metal contents of plants collected by both quadrat (samples A, B, C, and D) and hand picking or grab methods (sample E) indicated no significant difference (Table 6). The variability of the data does not allow a conclusion to be drawn in respect to the value of either sampling technique.

Correlation of heavy metal content and uptake with the percent of *Cyperus* in the quadrat

40. The percentage of *Cyperus* species by weight collected at each field site is shown in Table 7. Competition effects of other plant species within a site were hypothesized as potentially influencing the heavy metal content and uptake of *Cyperus*. Accordingly, a statistical examination was made to see if the lower biomass of *Cyperus* might have higher metal contents and lower metal uptake reflecting a dilution effect. A statistical examination did not evidence any correlation between the percent of *Cyperus* in the collected biomass and either concentration or uptake of heavy metals. The percent of *Cyperus* in the collected biomass was not correlated to either concentration or uptake of heavy metals.

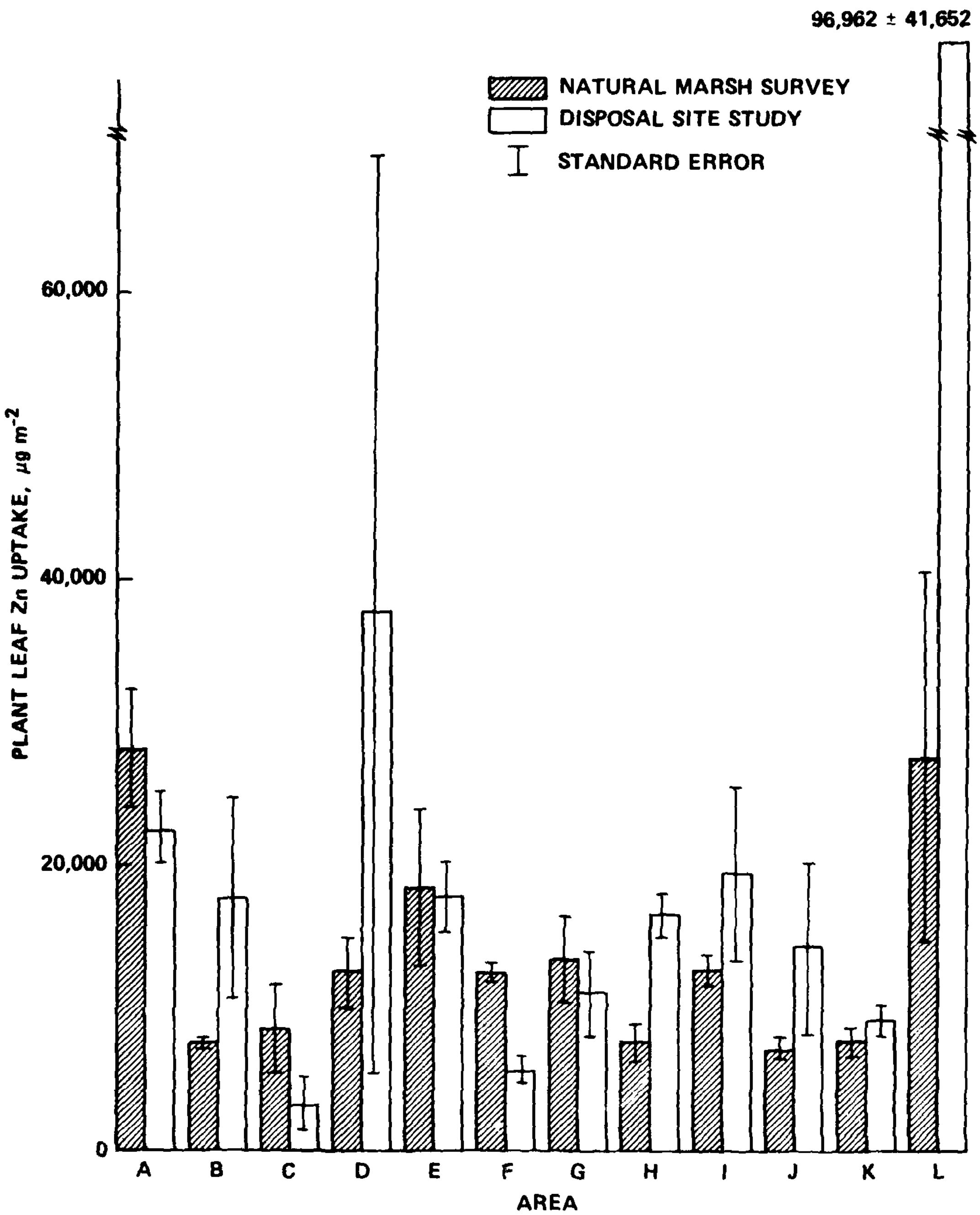

Figure 25. Total zinc uptake by *S. alterniflora* in natural marshes and disposal sites

Heavy metal
content of *Cyperus* tissue

41. The leaf heavy metal concentrations of the morphologically similar species of *Cyperus*, *C. esculentus*, *C. odoratus (= ferugineseens)*, *C. strigosus*, and *C. Englemanni* (Appendix G) collected from natural freshwater marsh areas were compared with those of *C. esculentus* var. *sativus* grown in the greenhouse study. The results of the previous greenhouse study indicated that, under upland (oxidized) conditions, *C. esculentus* had higher concentrations of Zn, Cd, Cu, Mn, and Pb, while Fe content was highest under flooded or reduced conditions. Concentrations of Ni, Cr, and Hg were the same under both disposal conditions. The watering protocol utilized in the upland portion of the greenhouse study approximated the conditions prevalent in *Cyperus* habitats. Most of the samples collected in the field were collected from areas that flooded during rains and subsequently dried out. Additionally, the Cyperaceae are among the first species present in disturbed areas; therefore they are collected only from the edges of the natural marsh, often near man-made structures. For this reason, the samples collected in the field might be expected to have the highest of the natural marsh Zn, Cd, Cu, and Pb levels. There are no literature values other than those of the greenhouse study available for comparison with the heavy metal content data discussed herein.

42. The total uptake values of *Cyperus* aboveground tissue were calculated for comparison to those determined during the greenhouse study. These data, converted to milligrams per square metre, appear in the following discussion as Tables 8-17. The uptake of heavy metals by *Cyperus* during the greenhouse study generally appears greater than that noted in the natural marsh. This phenomenon is directly related to the greater biomass developed under the greenhouse conditions, the nutrient contents of the sediment, and the absence of the competition from other early successional plants.

43. Arsenic. The plant leaf tissue content of As was never greater than 0.35 $\mu g\ g^{-1}$ and usually was below detection levels (Figure 26). This is essentially the same distribution found in the

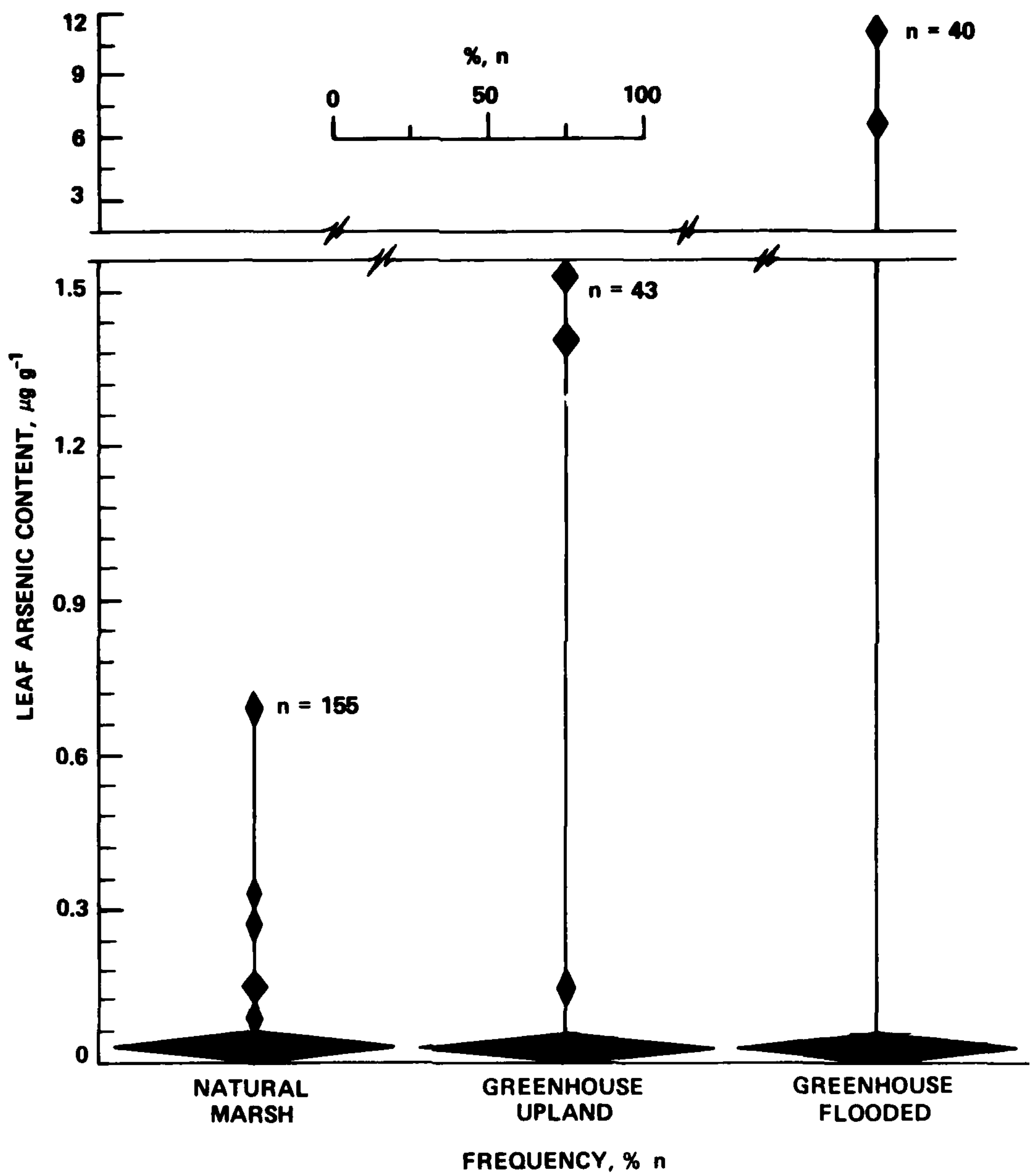

Figure 26. Distribution of arsenic concentrations, *Cyperus* species

greenhouse study. Arsenic contents of plants grown under flooded conditions in the greenhouse were as high as 14 μg g^{-1} on sediments highly contaminated with 316 μg g^{-1} total As. Arsenic uptake by *Cyperus* was negligible (Table 8). This may have been the result of volitization of As during the hot acid digestion procedures prior to analysis.

44. Cadmium. Cadmium concentrations were found to be considerably lower than those of the greenhouse upland plants and slightly less than those of the greenhouse flooded group. As the field collections were made principally from areas presumed to be oxidized substrate similar to the greenhouse upland, the contrast is greater (Figure 27). No collection sites were found to contain consistently high Cd levels. Most samples contained less than 0.75 μg g^{-1} and none exceeded 3.50 μg g^{-1} Cd. The total uptake of Cd by the natural marsh *Cyperus* was usually less than 0.10 mg m^{-2} and invariably less than that of the greenhouse study (Table 9). Plant uptake of Cd under greenhouse conditions could be expected to be greater since the growth environment was free from competitive plants and other adverse growing conditions that could occur in the field. These data indicate that plant uptake of Cd from dredged material should be of concern and should be monitored.

45. Chromium. The level of Cr in natural marsh plants ranged from 0.0 to 33.23 μg g^{-1} (Figure 28). These levels were higher than those determined in *Cyperus* from either greenhouse disposal condition. The highest consistent levels were found in the MC area and at ME3 (Figure 7). There appeared to be no pattern in the location of the plants with higher Cr levels in the field. *Cyperus* leaves were rinsed with deionized reverse osmosis (RO) water before processing. Leaf surface adsorbed Cr could account for the higher contents of leaf Cr in marsh samples versus the greenhouse-grown plants. Washing *S. alterniflora* leaves appeared to result in lower Cr content, but this difference was not statistically significant in this study. Chromium uptake was less than 1 mg m^{-2} (Table 10). Greater plant biomass production in the greenhouse study would explain the larger Cr uptake in the greenhouse plants.

46. Copper. The mean Cu concentration in the natural marsh was

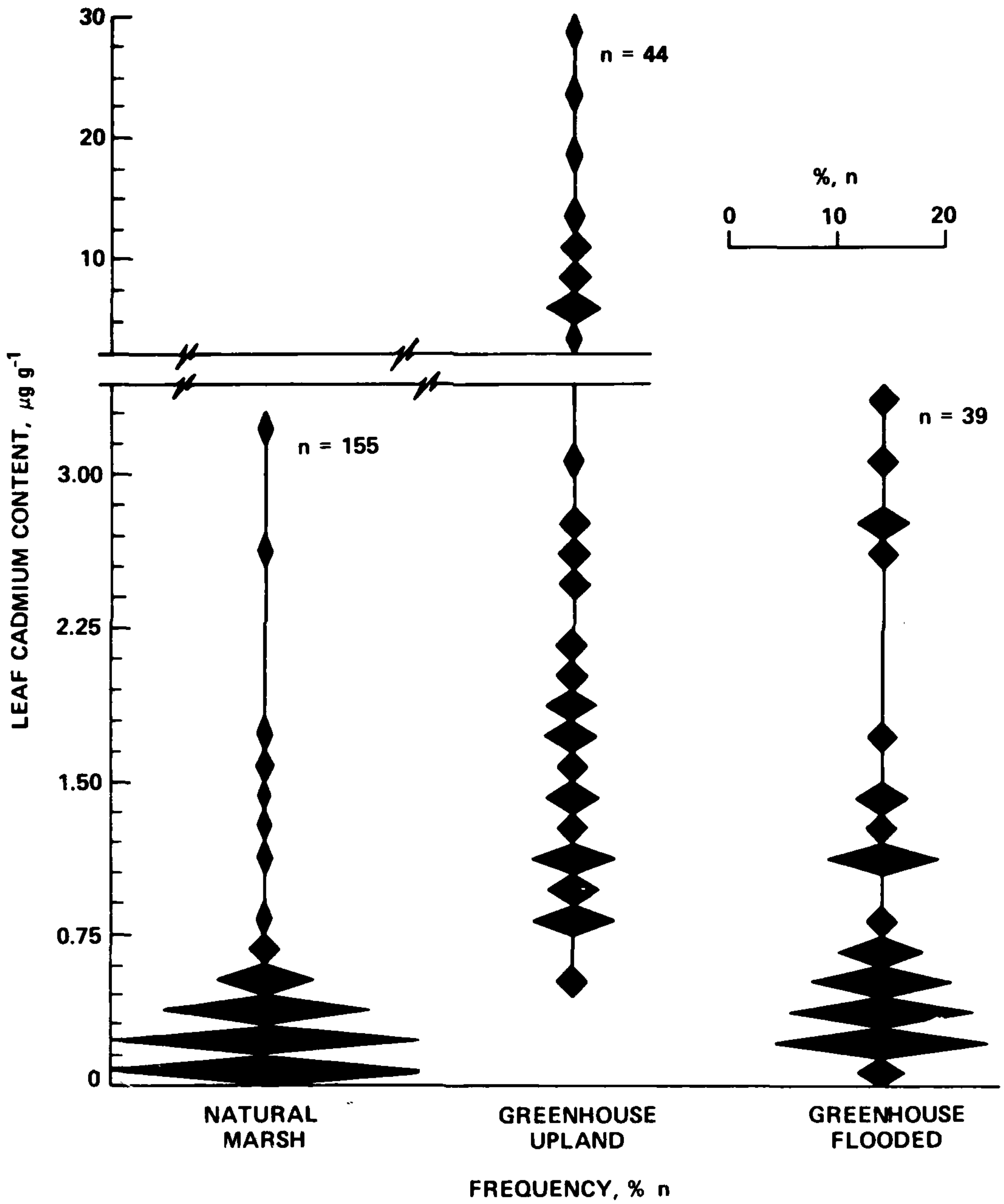

Figure 27. Distribution of cadmium concentrations, *Cyperus* species

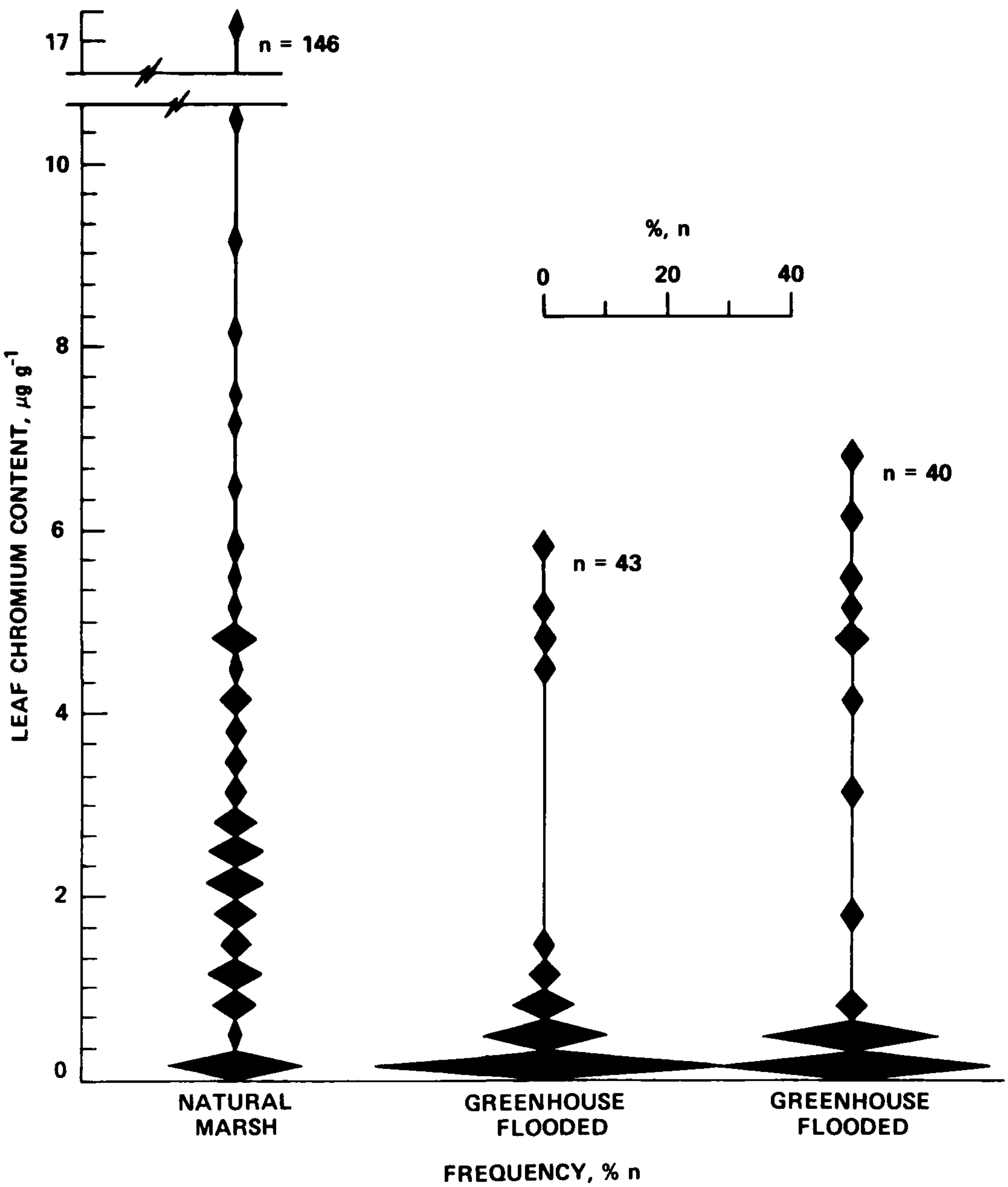

Figure 28. Distribution of chromium concentrations, *Cyperus* species

8.2 μg g^{-1}, a value significantly higher than the means of 3.7 and 2.7 μg g^{-1} for the upland and flooded greenhouse plants, respectively (Figure 29). While no area yielded plants with uniformly high Cu concentrations, the higher levels were usually associated with the MC collections (Figure 7). Collections from this area generally contained from 5.0 to 23 μg g^{-1} Cu. The overall range of Cu for all *Cyperus* samples was 0.0 to 26.8 μg g^{-1} with no variation attributable to species differences. Total uptake of Cu was usually less than that measured in the greenhouse study (Table 11). The larger biomass production of greenhouse plants would explain the larger plant Cu uptake in the greenhouse study.

47. Iron. Iron concentrations ranged from 28 to 1873 μg g^{-1} with a mean of 166 μg g^{-1}. This concentration was higher than those of the greenhouse flooded and upland disposal environments (Figure 30). The concentrations of the samples at MC11 (Figure 7) were the highest, ranging from 498 to 1893 μg g^{-1}. There were no obvious sources of Fe at the site such as refuse. Iron total uptake values ranged from 1 to 36 mg m^{-2}. This range is similar to that of the greenhouse upland condition, 1 to 48 mg m^{-2}, and the greenhouse flooded, 0.5 to 35 mg m^{-2} of Table 12.

48. Lead. The mean of the Pb concentrations in the natural marsh *Cyperus* was 6.07 μg g^{-1}, representing a range of 0.0 to 85.20 μg g^{-1}. These levels were significantly greater than either the greenhouse flooded or upland means of 1.05 and 1.20 μg g^{-1}, respectively (Figure 31). No field sites were associated with either consistently high levels, over 5 μg g^{-1}, or low levels, less that 5 μg g^{-1}. While the helicopter with nonleaded fuel should have eliminated the possibility of additional airborne Pb contamination of plant leaves, the deionized RO water rinse may not have removed previous airborne Pb contamination of collected leaves. This could explain the higher Pb content in field-collected leaves when compared to the greenhouse plants. Total uptake of Pb was generally less in natural marsh *Cyperus* than either upland or flooded greenhouse values (Table 13). The greater biomass production of greenhouse-grown plants would explain the larger total uptake of Pb in the greenhouse study plants.

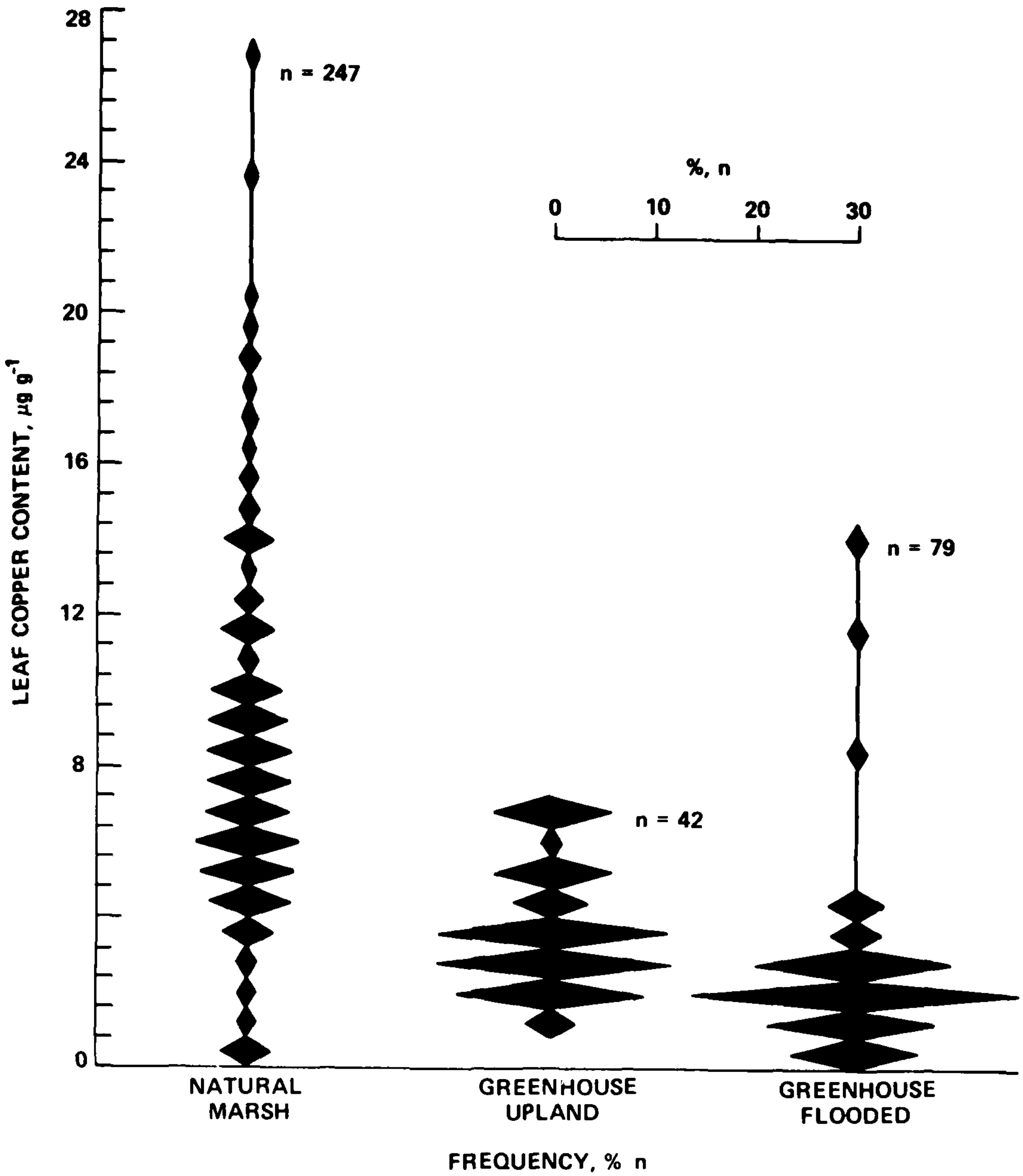

Figure 29. Distribution of copper concentrations, *Cyperus* species

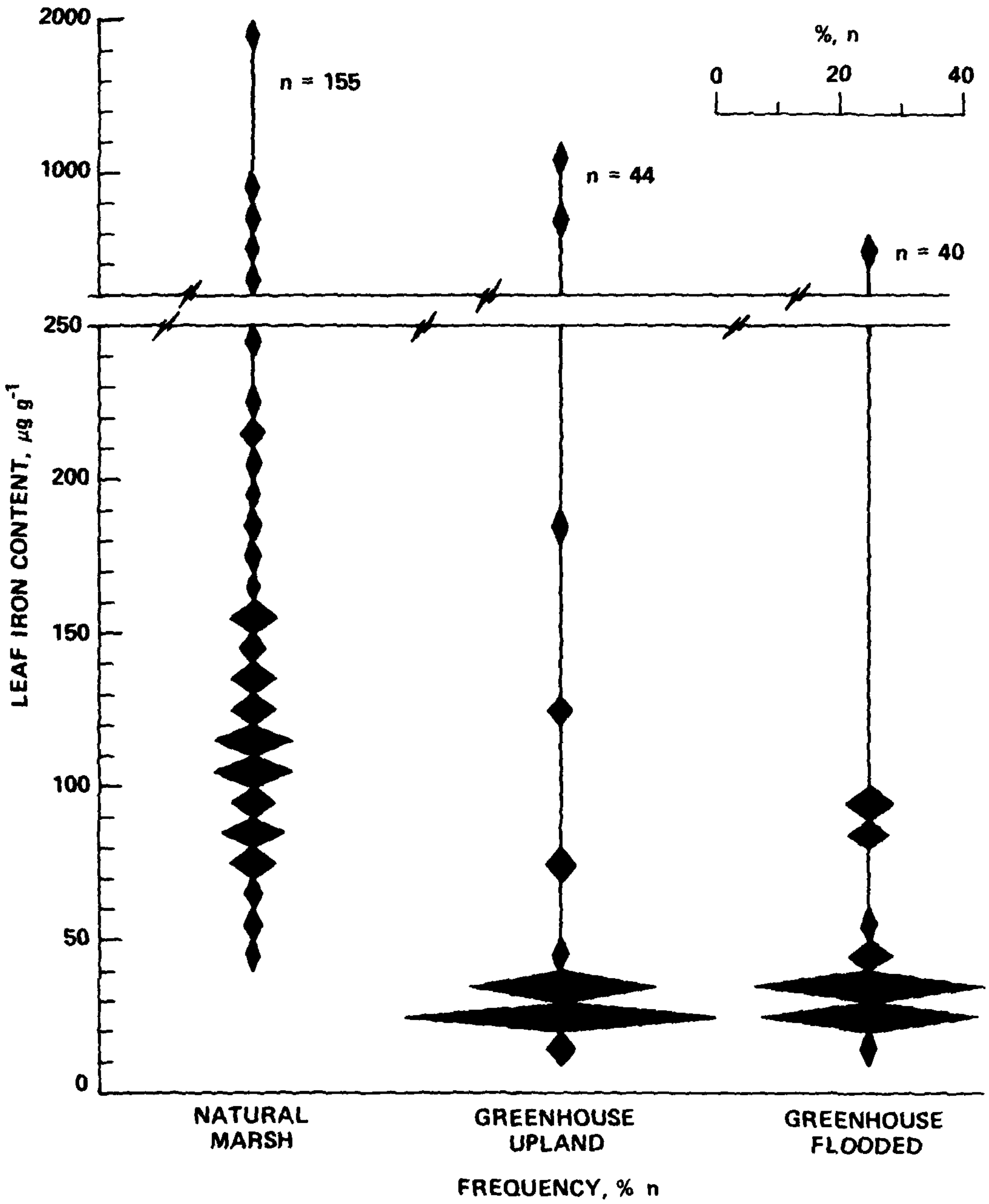

Figure 30. Distribution of iron concentrations, *Cyperus* species

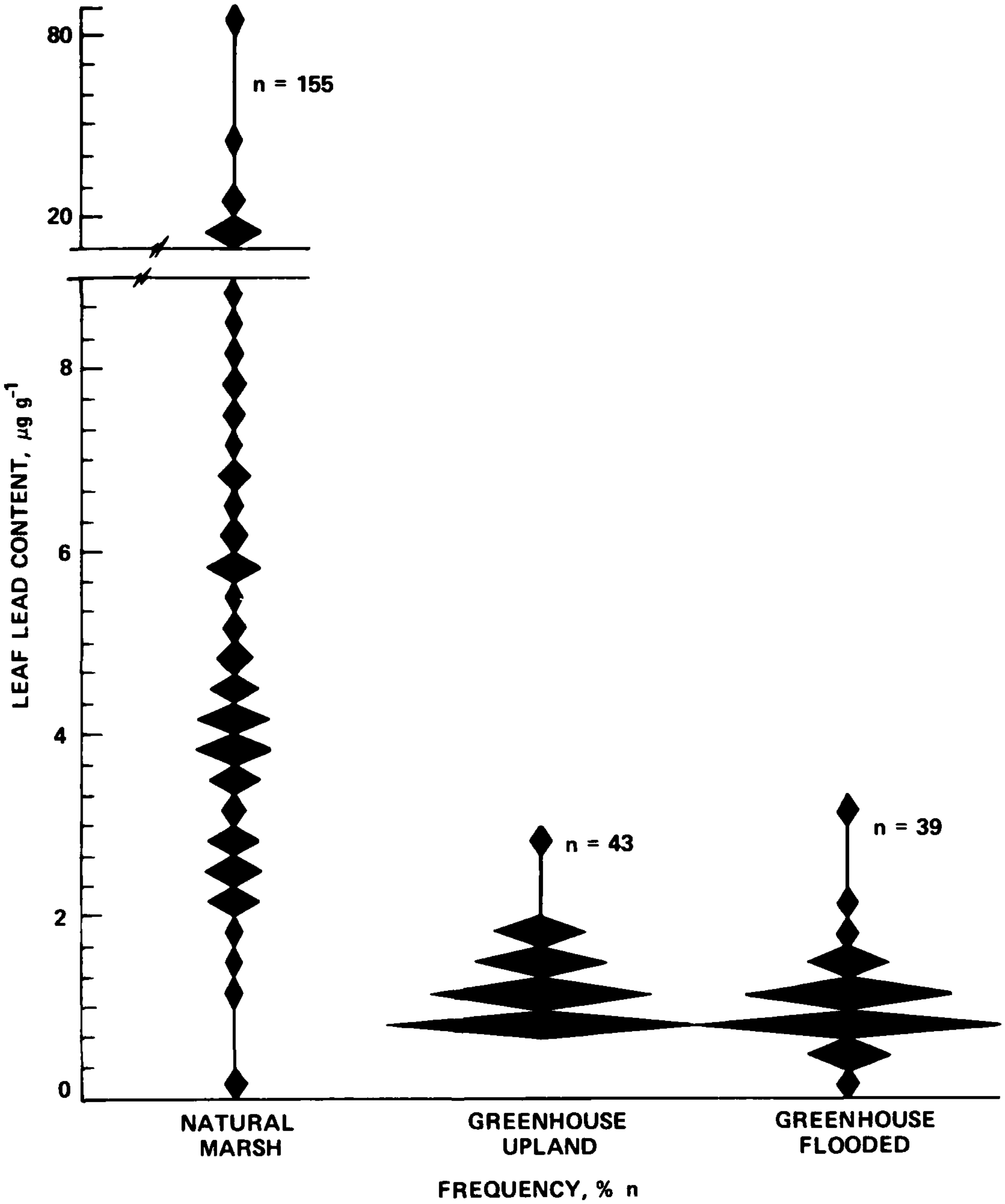

Figure 31. Distribution of lead concentrations, *Cyperus* species

49. Manganese. In contrast to Cr, Cu, Fe, and Pb, Mn leaf tissue concentration was lower in the natural marsh than in either treatment in the greenhouse study (Figure 32). The range of Mn concentrations in natural marsh *Cyperus* was 19 to 551 $\mu g\ g^{-1}$, with a mean of 158 $\mu g\ g^{-1}$. Manganese concentrations were not uniformly high or low at any location. In the natural marsh, there was a reversal of the Fe-Mn ratio of the greenhouse study, or the Mn concentrations were lower than those of Fe. The total uptake values for Mn in natural marsh *Cyperus* ranged from 0.6 to 50 $mg\ m^{-2}$. These total uptake values are generally lower than those of either upland or flooded conditions in the greenhouse study treatments (Table 14).

50. Mercury. Concentration of Hg in natural marsh *Cyperus* seldom exceeded 0.02 $\mu g\ g^{-1}$, a value slightly lower than either of the greenhouse treatments (Figure 33). Sites DE1, DE2, and DE3 (Figure 7) appeared to have the highest levels of Hg, up to 2.0 $\mu g\ g^{-1}$. These low values for Hg may be a result of gaseous loss of Hg during the hot acid digestion of the plant material. Total uptake of Hg by *Cyperus* from the natural marsh was negligible (Table 15).

51. Nickel. The Ni concentrations in the leaf tissue of *Cyperus* from the natural marsh ranged from 0 to 14.1 $\mu g\ g^{-1}$ (Figure 34). The distribution of values was relatively uniform and most values were significantly higher than the values reported in the greenhouse study. No single area yielded plants with uniformly high or low concentrations. The deionized RO water rinse may not have washed airborne particulate Ni contamination from the plant leaves and therefore could explain the higher leaf Ni contents from the field collections. Biomass production and Ni uptake of the greenhouse plants was usually greater than that of the field-grown plants (Table 16).

52. Zinc. Zinc concentrations in the natural marsh *Cyperus* ranged from 0 to 317 $\mu g\ g^{-1}$ (Figure 35). The mean of the natural marsh plant concentrations, 79 $\mu g\ g^{-1}$, was less than that of the greenhouse upland plants, 122 $\mu g\ g^{-1}$, and slightly higher than that of the greenhouse flooded plants, 67 $\mu g\ g^{-1}$. Since the field substrate conditions were presumed to be similar to the conditions in the greenhouse upland

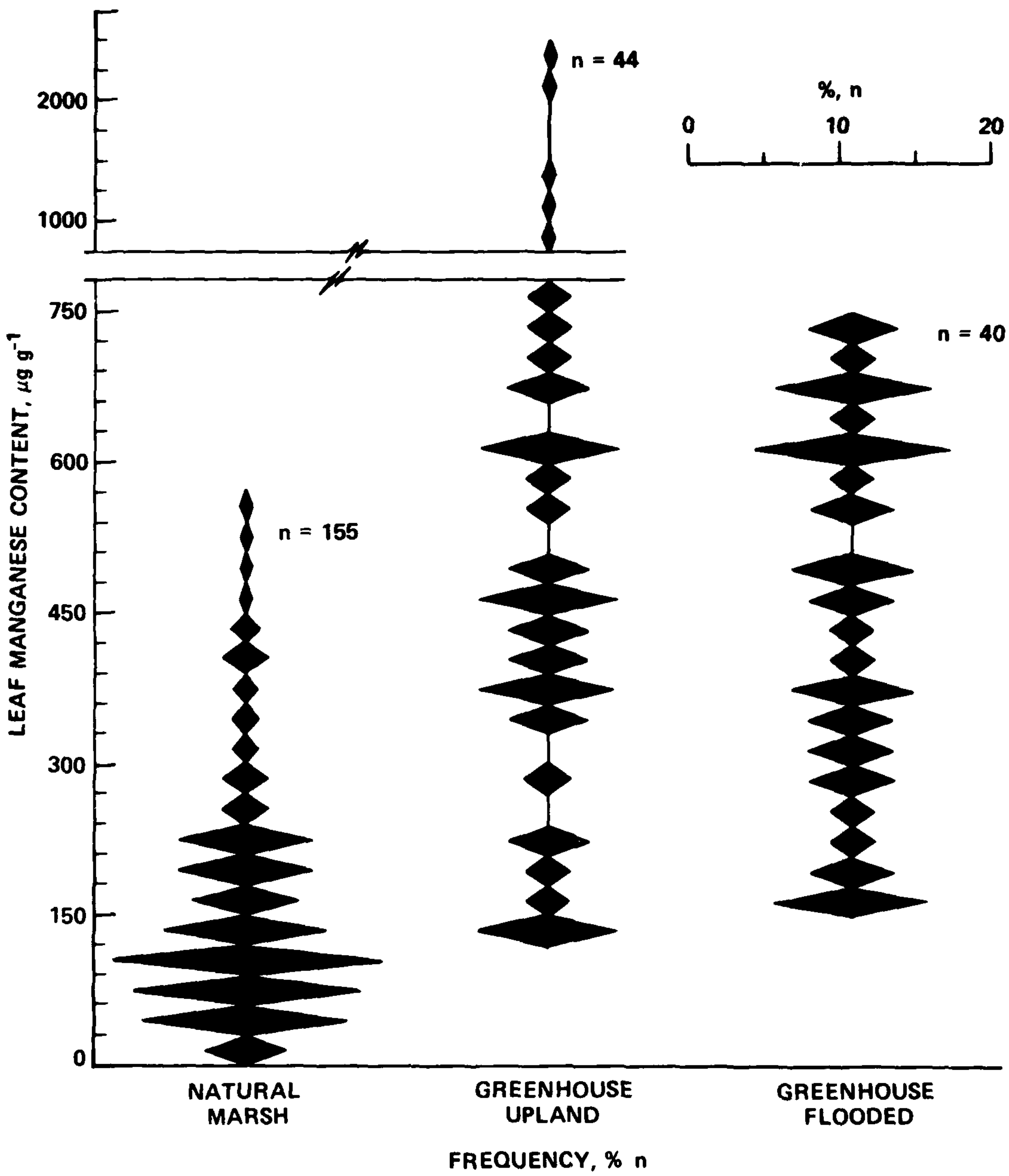

Figure 32. Distribution of manganese concentrations, *Cyperus* species

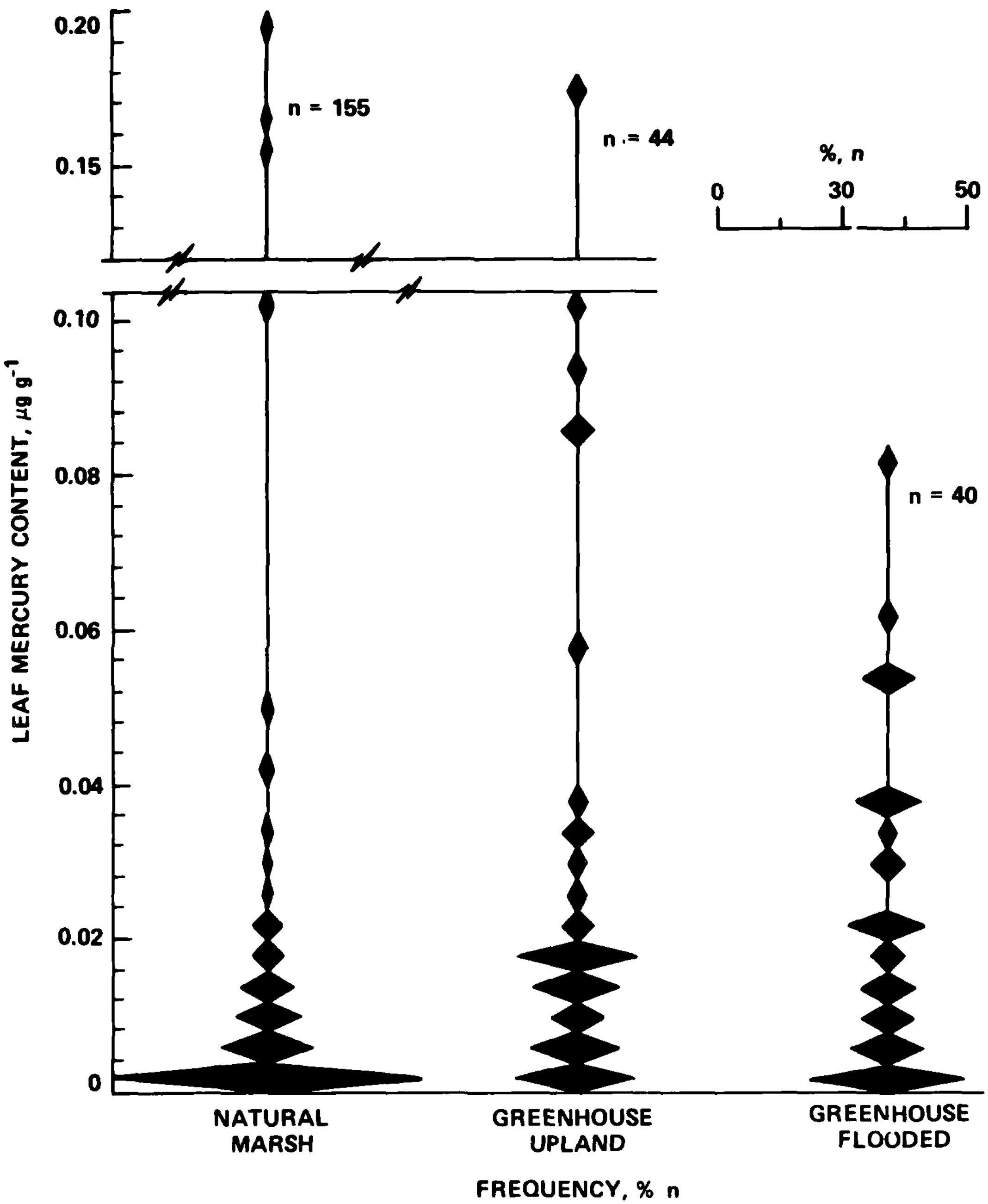

Figure 33. Distribution of mercury concentrations, *Cyperus* species

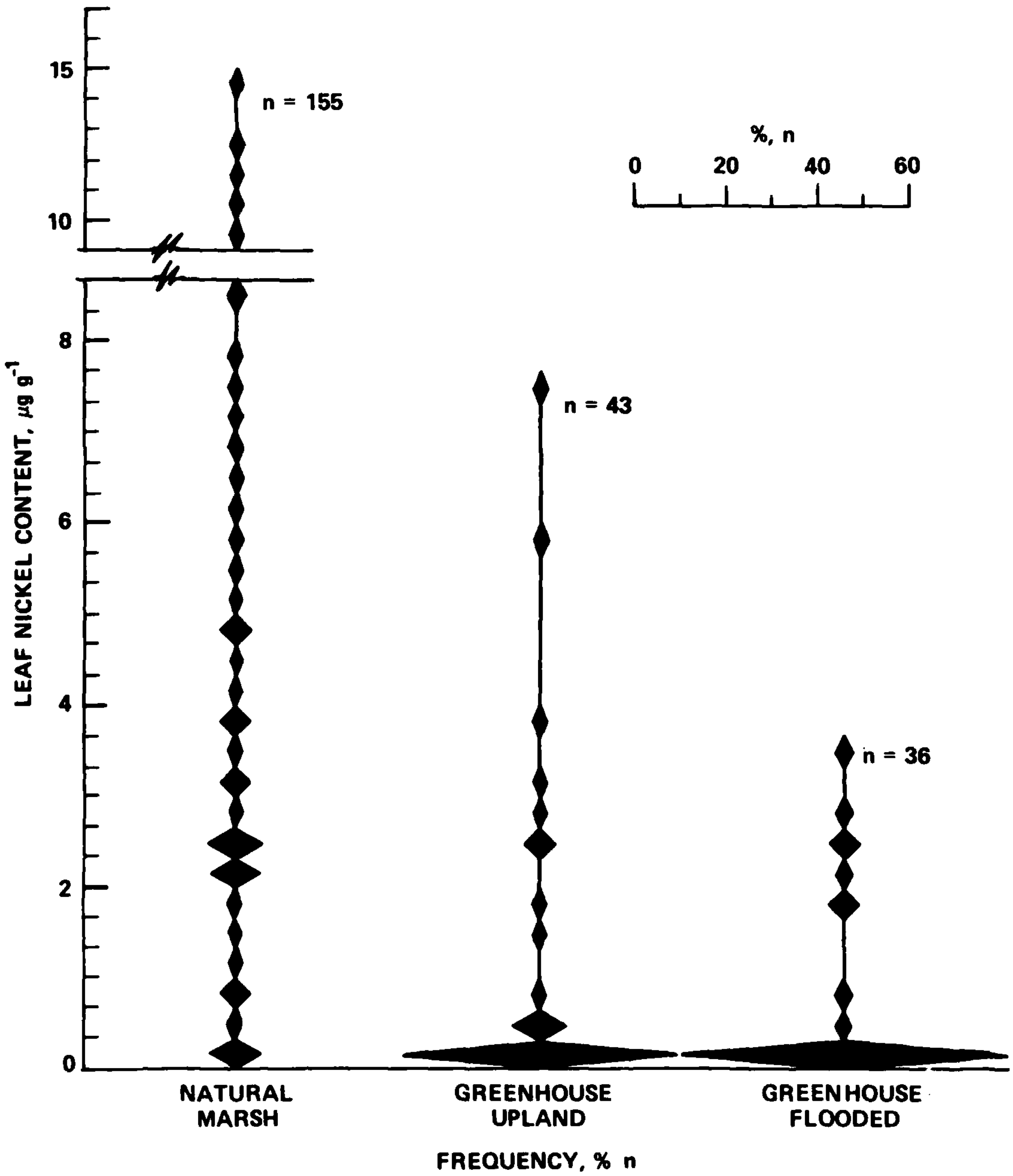

Figure 34. Distribution of nickel concentrations, *Cyperus* species

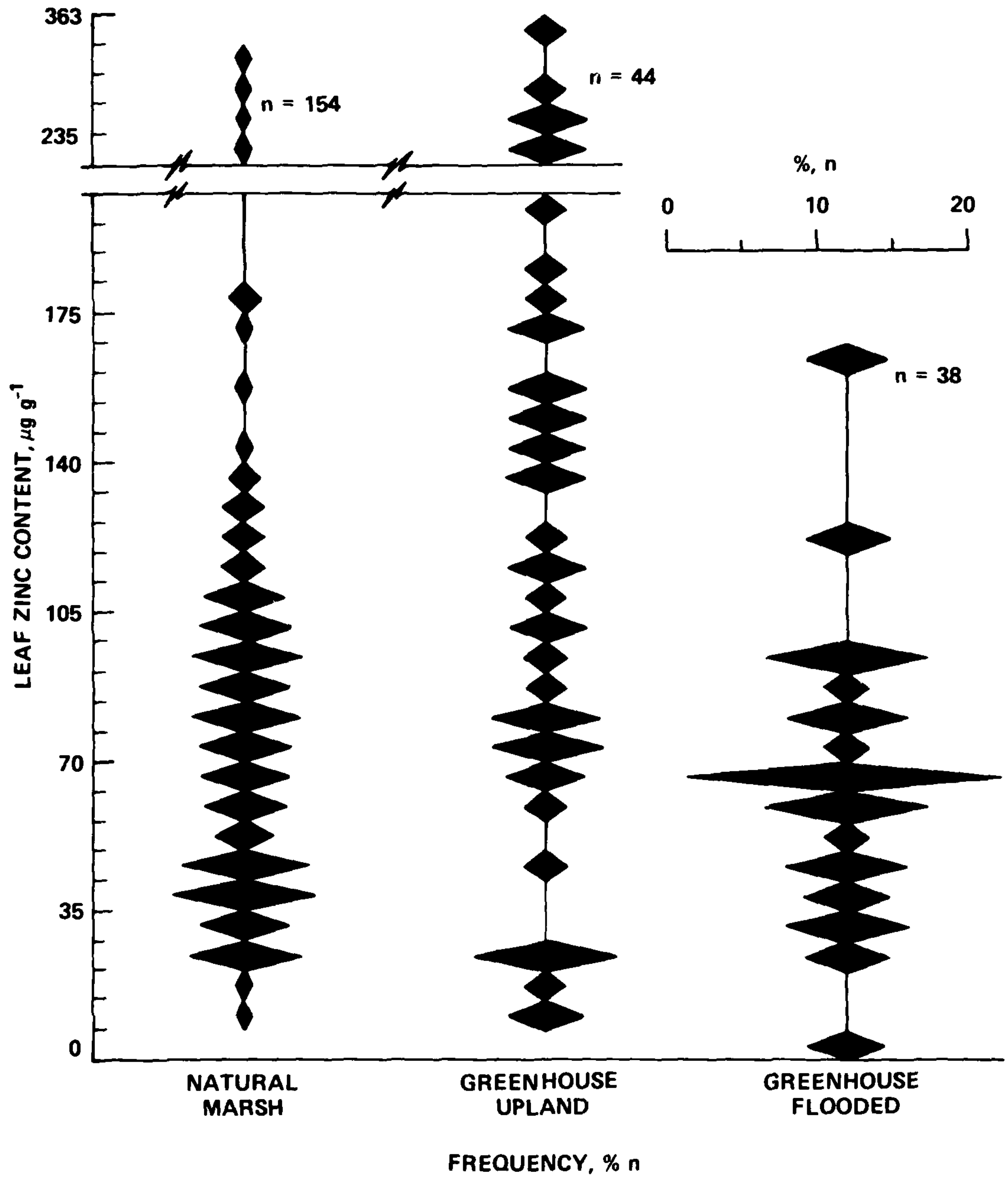

Figure 35. Distribution of zinc concentrations, *Cyperus* species

environment where Zn uptake was found to be greater, it appears that Zn concentrations may be lower in the natural marsh. Uniformly high levels in the vicinity of 100 to 200 $\mu g\ g^{-1}$ were found in plants collected at MC11 and MC12 (Figure 7). There were no obvious factors influencing the elevated Zn levels in these natural marsh areas. The total uptake of Zn by *Cyperus* aboveground tissue was generally lower in the natural marsh (Table 17). Sites MC11 and MC12, two field sites exhibiting high Zn concentration, did not show correspondingly high plant uptake values. These data indicate that the high Zn contents were related to small plants as a concentration effect due to plant size. Since the greenhouse plants produced more biomass than field-grown plants, it follows that Zn uptake was greater in the greenhouse plants.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

53. Heavy metal concentrations in marsh plants sampled in natural stands were quite similar in range to those concentrations observed in plants collected from CE disposal sites and those grown in contaminated sediments in the greenhouse. Exceptions were the lower Mn and Zn contents of *S. alterniflora* sampled in the natural saltwater marsh and lower Mn and Fe contents of *Cyperus* species sampled in the natural freshwater marsh. These data indicate that, if a contaminated dredged material is placed in a flooded disposal environment, the marsh plants colonizing that area should contain heavy metals in levels similar to those of natural marsh plants in the vicinity of the dredged material disposal.

54. A comparison of total plant heavy metal uptake values of natural saltwater marsh plants with those of disposal site plants of the same geographical area indicated a generally higher Cd total uptake in the disposal site plants. This is related to the larger biomass production on the disposal sites versus the natural marsh. The reader must remember that Cd contents and uptakes have been compared for different years and the conclusions may not be true if plants were collected from disposal sites and their associated natural marshes during the same growing season.

55. Additional research is needed to more accurately establish the relationship among heavy metal uptake by marsh plants growing in disposal sites and in adjacent natural marshes during the same growing season of the same year. Both saltwater and freshwater environments need to be studied.

56. This report conclusively indicates that dredged material containing elevated Cd concentrations should not be disposed in an upland environment, but rather in a flooded (reduced) environment. Placing a Cd-enriched dredged material in a flooded environment should result in marsh plants containing Cd levels equal to or less than those corresponding values of adjacent, naturally occurring marsh plants. Consequently, the environmental impact of disposing of a Cd-enriched dredged material should be minimized under such a flooded disposal environment.

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Table 1

Techniques Used in the Analysis of Nitric Acid Digests

Chemical Species	Procedures and/or Instrumentation	Lowest Reporting Concentration $\mu g\ g^{-1}$
Zn*	Determined with a Spectrametrics Argon Plasma Emission Spectrophotometer Model II	0.1000
Cd*		0.1000
Cu*		0.1000
Fe*		0.1000
Mn*		0.1000
Ni*		0.1000
Cr*		0.1000
Pb*		0.1000
As	Determined with a Nisseisangyo Isotope Shift Zeeman Effect Atomic Absorption Spectrophotometer	0.0010
Hg	Cold Vapor Flameless Atomic Absorption *Standard Methods***	0.0002

* Determined with a Perkin-Elmer Heated Graphite Atomizer Absorption Unit to reach (all in $\mu g\ g^{-1}$) 0.0001 Cd, 0.004 Zn, 0.001 Cu, 0.0005 Fe, Mn, and Pb, 0.003 Ni, 0.001 Cr.

** American Public Health Association (1976).

Table 2

Comparison of Leaf Heavy Metal Contents of Flooded and Upland Collections of *S. alterniflora*

Metal	Mean Leaf Concentration, $\mu g\ g^{-1}$ Flooded	Upland	Level of Significance
Arsenic	0.208	0.0134	NS*
Cadmium	0.08	0.07	NS
Chromium	2.49	2.38	NS
Copper	3.1	3.5	NS
Iron	128	140	NS
Lead	2.1	2.6	NS
Manganese	61	72	NS
Mercury	0.015	0.016	NS
Nickel	1.7	2.2	NS
Zinc	22	34	NS

* NS = Not significant.

Table 3

Comparison of Leaf Heavy Metal Contents of Washed and Unwashed Portions of Samples of *S. alterniflora*

Metal	Mean Leaf Concentrations, $\mu g\ g^{-1}$ Washed	Unwashed	Level of Significance
Arsenic	0.009	0.021	NS*
Cadmium	0.10	0.23	0.05
Chromium	2.21	2.53	NS
Copper	4.1	3.9	NS
Iron	191	143	NS
Lead	2.4	2.1	NS
Manganese	72	75	NS
Mercury	0.016	0.019	NS
Nickel	1.9	1.7	NS
Zinc	25	32	NS

* NS = Not significant.

Table 4

Areas of Comparison of Natural Marsh Survey and Disposal Site Study of Heavy Metal Concentration and Uptake for *S. alterniflora*

Area*	North Latitude	West Longitude	Natural Marsh Site	Disposal Site**
A	41°00'-41°30'	72°40'-73°10'	NY1-NY6	1-1
B	39°01'-39°44'	74°40'-74°42'	NY10-NY12	2-1, 2-3
C	38°20'-38°50'	70°10'-76°30'	BM7	3-2-3-6
D	33°30'-34°00'	77°56'-78°32'	JV10, JV11	4-1, 4-2
E	31°50'-32°10'	80°50'-81°10'	JV4, JV5	5-1
F	31°01'-31°53'	81°01'-81°40'	JV3, JV4	5-2
G	30°20'-31°05'	81°25'-81°35'	JV1-JV3	5-2, 3, 4, 6-1-6-3
H	29°13'-29°26'	89°33'-90°57'	NO6-NO10	8-1
I	29°10'-29°15'	90°04'-90°57'	NO8-NO10	8-2
J	29°01'-29°54'	93°56'-94°53'	CC13-CC15	10-1-10-3
K	28°10'-28°40'	96°06'-96°57'	CC7-CC11	11-1, 11-2
L	27°40'-28°05'	97°20'-97°30'	CC1-CC6	11-3

* See Figure 8 for locations of designated areas.
** Locations in code used in Lee, Sturgis, and Landin (1978).

Table 5

Mean Yield of Aboveground Tissue of *S. alterniflora* on Natural Marsh and Disposal Sites

Area*	Natural Marsh, 1978, g m^{-2}	Disposal Site, 1975, g m^{-2}
A	627	1095
B	718	801
C	716	214
D	1078	1659
E	1585	1106
F	1860	691
G	1184	904
H	649	1044
I	577	1250
J	438	658
K	613	774
L	505	699

* See Figure 8 for locations of designated areas.

Table 6

Comparison of Heavy Metal Contents of Grab and Quadrat Samples of *Cyperus*

Metal	Mean Leaf Concentrations, $\mu g\ g^{-1}$ Grab	Quadrat	$\alpha = 0.05$ Level of Significance
Arsenic	0.032	0.026	NS*
Cadmium	0.40	0.35	NS
Chromium	2.68	2.40	NS
Copper	7.6	8.4	NS
Iron	158	168	NS
Lead	4.7	6.4	NS
Manganese	145	161	NS
Mercury	0.012	0.016	NS
Nickel	3.5	3.5	NS
Zinc	83	79	NS

* NS = Not significant.

Table 7

Percent of *Cyperus* by Weight in Quadrat Biomass

Site	Percent
DE1	26.9
DE2	68.6
DE3	54.9
DE4	49.6
DE5	54.5
DE6	40.0
DE7	43.5
DE8	44.4
DE9	25.8
IN1	23.6
MC1	53.7
MC2	66.7
MC3	59.3
MC4	43.6
MC5	45.3
MC6	39.8
MC7	50.7
MC8	47.5
MC9	63.8
MC10	63.2
MC11	39.1
MC12	19.6
MC13	27.4
ME1	19.1
ME2	22.3
ME3	10.5
ME4	53.1
ME5	31.6
ME6	53.3
MW1	42.4
MW2	40.4

Table 8

Total Uptake of Arsenic by Aboveground

Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	<0.01	<0.01	<0.01
2		<0.01	<0.01
3		<0.01	<0.01
4		--	--
5		--	--
6		--	--
7		--	--
8		--	--
9		--	--
IN1		<0.01	<0.01
2	--	<0.01	<0.01
3	--	<0.01	0.05
MC1	<0.01	<0.01	<0.01
2		<0.01	<0.01
3		<0.01	<0.01
4		--	--
5		--	--
6		--	--
7		--	--
8		--	--
9		--	--
10		--	--
11		--	--
12		--	--
13		--	--
ME1		<0.01	<0.01
2		<0.01	<0.01
3		2.45	<0.01
4		--	--
5	0.09	--	--
6	<0.01	--	--
MW1		<0.01	<0.01
2		<0.01	<0.01
3	--	<0.01	<0.01

* Abbreviations are the same areas as those shown in Figure 7.

Table 9

Total Uptake of Cadmium by Aboveground Tissue of *Cyperus* Species

	Total Uptake, mg m^{-2}		
		Greenhouse	
Location*	Natural Marsh	Upland	Flooded
DE1	0.01	1.16	0.24
2	0.08	15.36	8.26
3	0.04	0.49	0.06
4	0.02	--	--
5	0.02	--	--
6	0.01	--	--
7	0.03	--	--
8	0.03	--	--
9	0.01	--	--
IN1	0.07	0.70	0.34
2	--	4.40	1.90
3	--	1.43	1.22
MC1	0.02	49.52	6.26
2	0.01	96.65	22.34
3	0.01	28.55	11.88
4	<0.01	--	--
5	0.01	--	--
6	0.02	--	--
7	0.02	--	--
8	0.01	--	--
9	0.04	--	--
10	<0.01	--	--
11	0.01	--	--
12	0.03	--	--
13	<0.01	--	--
ME1	<0.01	2.47	1.41
2	<0.01	0.56	1.53
3	<0.01	16.28	0.05
4	<0.01	--	--
5	0.01	--	--
6	0.20	--	--
MW1	0.01	53.22	7.39
2	0.01	3.21	0.94
3	--	1.92	0.70

* Abbreviations are the same areas as those shown in Figure 7.

Table 10

Total Uptake of Chromium by Aboveground Tissue of *Cyperus* Species

	Total Uptake, mg m^{-2}		
		Greenhouse	
Location*	Natural Marsh	Upland	Flooded
DE1	0.05	0.11	0.06
2	0.88	0.92	1.77
3	0.00	0.03	0.06
4	0.47	--	--
5	0.39	--	--
6	0.16	--	--
7	0.26	--	--
8	0.03	--	--
9	0.05	--	--
IN1	0.06	0.14	0.65
2	--	1.22	2.21
3	--	0.80	3.58
MC1	0.07	IS**	14.59
2	0.05	24.20	21.64
3	0.05	7.74	16.19
4	0.04	--	--
5	0.04	--	--
6	0.18	--	--
7	0.15	--	--
8	0.13	--	--
9	0.23	--	--
10	0.07	--	--
11	0.10	--	--
12	0.04	--	--
13	0.01	--	--
ME1	0.03	0.21	0.99
2	0.09	0.58	0.57
3	0.09	0.99	0.11
4	0.22	--	--
5	0.20	--	--
6	0.74	--	--
MW1	0.17	0.62	26.72
2	0.04	0.41	0.18
3	--	1.12	0.53

* Abbreviations are the same areas as those shown in Figure 7.
** IS = Insufficient sample for analysis.

Table 11

Total Uptake of Copper by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	0.54	1.05	1.27
2	1.09	6.55	9.52
3	0.50	1.37	0.48
4	0.67	--	--
5	0.82	--	--
6	0.68	--	--
7	1.08	--	--
8	0.83	--	--
9	0.29	--	--
IN1	0.27	1.55	1.91
2	--	3.98	0.86
3	--	2.96	9.93
MC1	0.37	16.39	7.74
2	0.33	27.85	18.21
3	0.32	13.59	12.63
4	0.22	--	--
5	0.22	--	--
6	0.70	--	--
7	0.77	--	--
8	0.51	--	--
9	1.38	--	--
10	0.61	--	--
11	0.35	--	--
12	0.29	--	--
13	0.29	--	--
ME1	0.14	5.52	14.00
2	0.13	1.00	5.96
3	0.29	7.82	0.72
4	0.24	--	--
5	0.23	--	--
6	1.80	--	--
MW1	0.15	27.52	21.18
2	0.04	5.07	6.07
3	--	4.76	5.11

* Abbreviations are the same areas as those shown in Figure 7.

Table 12

Total Uptake of Iron by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
	Natural Marsh	Greenhouse	
		Upland	Flooded
DE1	10.30	1.80	0.90
2	35.71	5.86	32.46
3	12.50	0.90	0.90
4	9.98	--	--
5	11.52	--	--
6	10.10	--	--
7	13.51	--	--
8	11.51	--	--
9	4.47	--	--
IN1	4.29	1.35	4.50
2	--	3.16	11.27
3	--	39.67	33.81
MC1	7.12	9.47	16.68
2	5.37	22.54	27.95
3	4.72	32.01	34.72
4	3.87	--	--
5	3.32	--	--
6	7.28	--	--
7	6.28	--	--
8	13.61	--	--
9	24.38	--	--
10	13.01	--	--
11	33.53	--	--
12	1.46	--	--
13	1.67	--	--
ME1	3.92	4.06	4.50
2	2.13	3.16	5.41
3	2.64	4.50	0.45
4	7.31	--	--
5	8.31	--	--
6	29.47	--	--
MW1	7.85	27.95	31.11
2	7.95	47.79	5.86
3	--	6.76	5.86

* Abbreviations are the same areas as those shown in Figure 7.

Table 13

Total Uptake of Lead by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
	Natural Marsh	Greenhouse Upland	Greenhouse Flooded
DE1	0.57	0.50	0.44
2	3.22	3.92	24.32
3	1.09	0.47	0.26
4	0.35	--	--
5	0.66	--	--
6	0.49	--	--
7	0.63	--	--
8	0.65	--	--
9	0.19	--	--
IN1	0.14	0.35	1.19
2	--	1.37	2.85
3	--	1.27	4.13
MC1	0.29	3.23	3.18
2	0.25	5.65	10.90
3	0.15	3.16	5.50
4	0.15	--	--
5	0.14	--	--
6	0.92	--	--
7	0.30	--	--
8	0.21	--	--
9	2.00	--	--
10	0.28	--	--
11	0.10	--	--
12	0.14	--	--
13	0.21	--	--
ME1	0.11	1.80	1.95
2	0.07	1.38	1.98
3	0.05	1.90	0.08
4	0.18	--	--
5	0.24	--	--
6	1.01	--	--
MW1	0.11	4.95	6.24
2	0.28	2.12	1.76
3	--	3.26	2.16

* Abbreviations are the same areas as those shown in Figure 7.

Table 14

Total Uptake of Manganese by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	6.22	6.3	5.86
2	50.22	158.70	207.39
3	13.60	16.23	18.94
4	8.09	--	--
5	10.49	--	--
6	4.31	--	--
7	3.17	--	--
8	10.08	--	--
9	6.12	--	--
IN1	3.02	46.89	121.28
2	--	317.85	233.54
3	--	50.95	131.65
MC1	6.18	99.19	243.91
2	6.80	271.87	296.21
3	2.83	154.19	130.30
4	4.10	--	--
5	4.54	--	--
6	4.68	--	--
7	4.53	--	--
8	13.77	--	--
9	4.20	--	--
10	11.95	--	--
11	5.63	--	--
12	0.59	--	--
13	2.24	--	--
ME1	14.00	44.18	121.73
2	7.63	60.41	47.79
3	6.58	185.75	6.76
4	12.17	--	--
5	20.10	--	--
6	41.18	--	--
MW1	7.15	288.10	235.35
2	7.49	89.27	136.61
3	--	30.21	104.15

* Abbreviations are the same areas as those shown in Figure 7.

Table 15

Total Uptake of Mercury by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	<0.01	0.02	<0.01
2	0.03	0.02	0.41
3	0.02	<0.01	<0.01
4	<0.01	--	--
5	<0.01	--	--
6	<0.01	--	--
7	<0.01	--	--
8	<0.01	--	--
9	<0.01	--	--
IN1	<0.01	<0.01	0.06
2	--	0.04	0.06
3	--	0.05	0.13
MC1	<0.01	0.20	0.06
2	<0.01	0.16	0.42
3	<0.01	0.06	0.21
4	<0.01	--	--
5	<0.01	--	--
6	<0.01	--	--
7	<0.01	--	--
8	<0.01	--	--
9	<0.01	--	--
10	<0.01	--	--
11	<0.01	--	--
12	<0.01	--	--
13	<0.01	--	--
ME1	<0.01	0.01	<0.01
2	<0.01	0.01	<0.01
3	<0.01	0.03	<0.01
4	<0.01	--	--
5	<0.01	--	--
6	<0.01	--	--
MW1	<0.01	0.05	0.02
2	<0.01	0.03	0.02
3	--	0.03	0.03

* Abbreviations are the same areas as those shown in Figure 7.

Table 16

Total Uptake of Nickel by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	0.07	IS**	IS
2	0.11	0.81	4.77
3	0.30	IS	IS
4	0.29	--	--
5	0.18	--	--
6	0.19	--	--
7	0.30	--	--
8	0.07	--	--
9	0.07	--	--
IN1	0.20	IS	IS
2	--	IS	IS
3	--	3.65	0.56
MC1	0.28	1.89	8.94
2	0.28	11.93	20.63
3	0.20	12.19	12.24
4	0.15	--	--
5	0.14	--	--
6	0.21	--	--
7	0.48	--	--
8	0.20	--	--
9	0.20	--	--
10	0.29	--	--
11	0.15	--	--
12	0.08	--	--
13	0.11	--	--
ME1	0.06	IS	IS
2	0.08	IS	0.66
3	0.13	5.71	IS
4	0.10	--	--
5	0.18	--	--
6	0.49	--	--
MW1	0.15	2.82	0.72
2	0.01	IS	IS
3	--	IS	0.21

* Abbreviations are the same areas as those shown in Figure 7.

** IS = Insufficient sample for analysis.

Table 17

Total Uptake of Zinc by Aboveground Tissue of *Cyperus* Species

Location*	Total Uptake, mg m^{-2}		
		Greenhouse	
	Natural Marsh	Upland	Flooded
DE1	7.47	55.36	49.77
2	18.59	591.52	986.38
3	5.04	118.39	85.93
4	4.31	--	--
5	3.22	--	--
6	2.72	--	--
7	8.88	--	--
8	12.98	--	--
9	4.33	--	--
IN1	4.09	40.39	62.39
2	--	213.79	194.95
3	--	194.95	321.32
MC1	1.97	719.12	300.67
2	1.31	781.78	561.31
3	2.51	311.86	268.21
4	1.18	--	--
5	1.40	--	--
6	5.27	--	--
7	6.69	--	--
8	3.35	--	--
9	9.60	--	--
10	3.77	--	--
11	2.71	--	--
12	3.88	--	--
13	1.92	--	--
ME1	3.11	40.44	51.67
2	2.03	87.19	120.65
3	1.34	27.99	4.50
4	4.12	--	--
5	5.06	--	--
6	37.75	--	--
MW1	3.05	1080.12	291.70
2	0.69	147.66	204.91
3	--	126.28	184.35

* Abbreviations are the same areas as those shown in Figure 7.

APPENDIX A: PHOTOGRAPHS OF SALTWATER AND FRESHWATER COLLECTION SITES

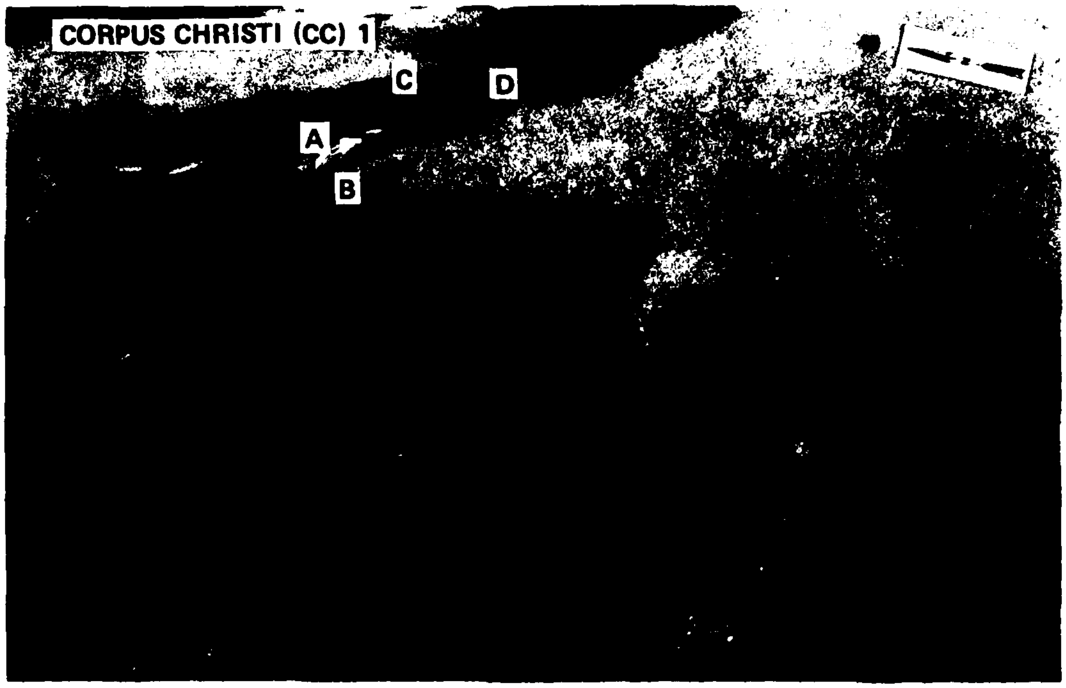


Photo 1. Site CC1

PHOTO NOT AVAILABLE ON
CORPUS CHRISTI SITE 2

Photo 2. Site CC2

CORPUS CHRISTI (CC) 3

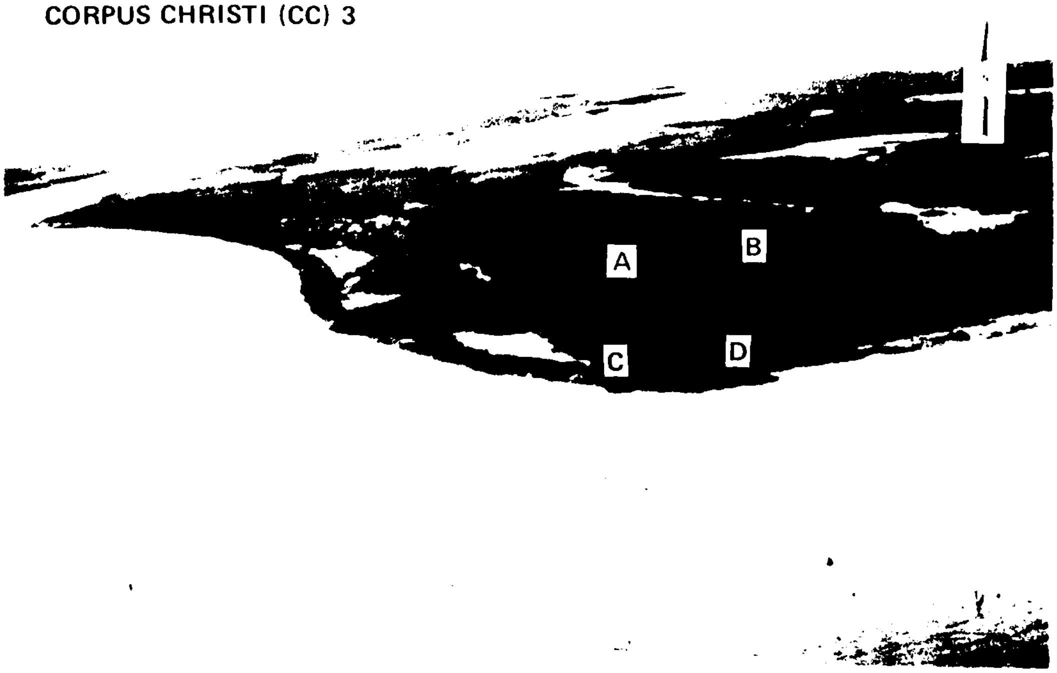


Photo 3. Site CC3

CORPUS CHRISTI (CC) 4

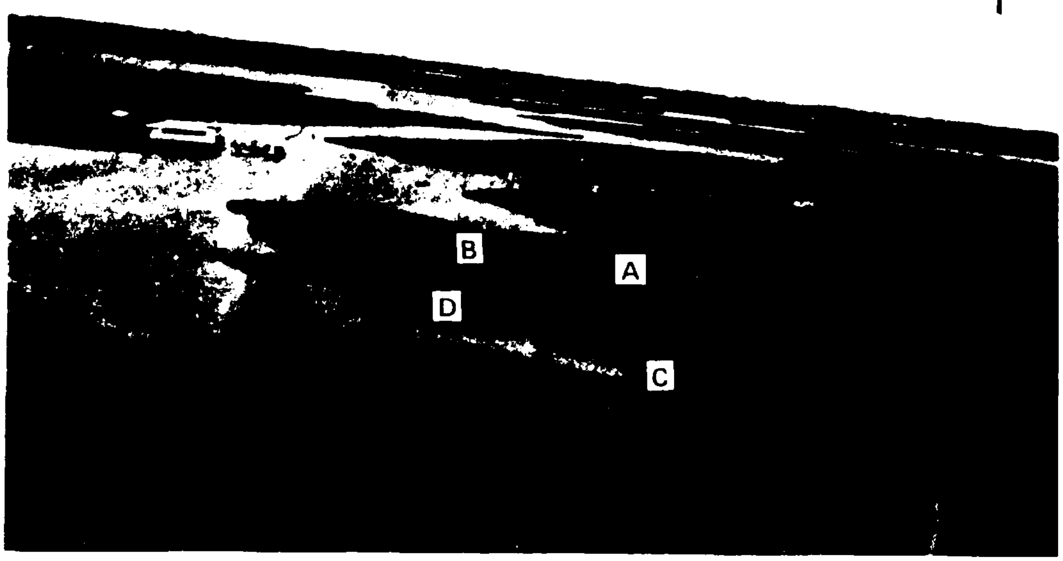


Photo 4. Site CC4

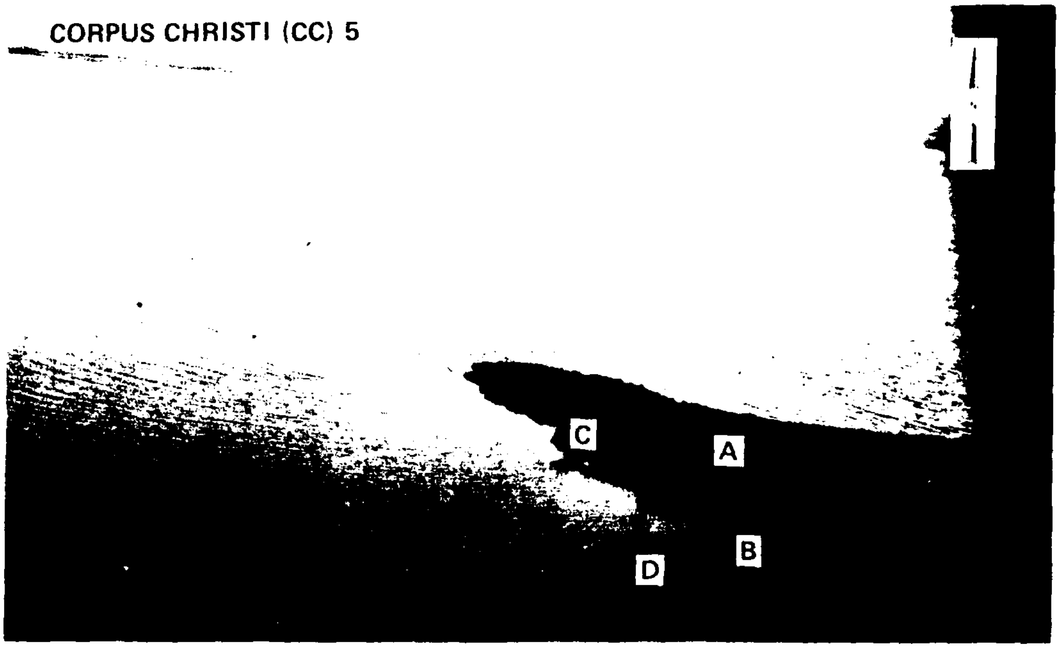


Photo 5. Site CC5

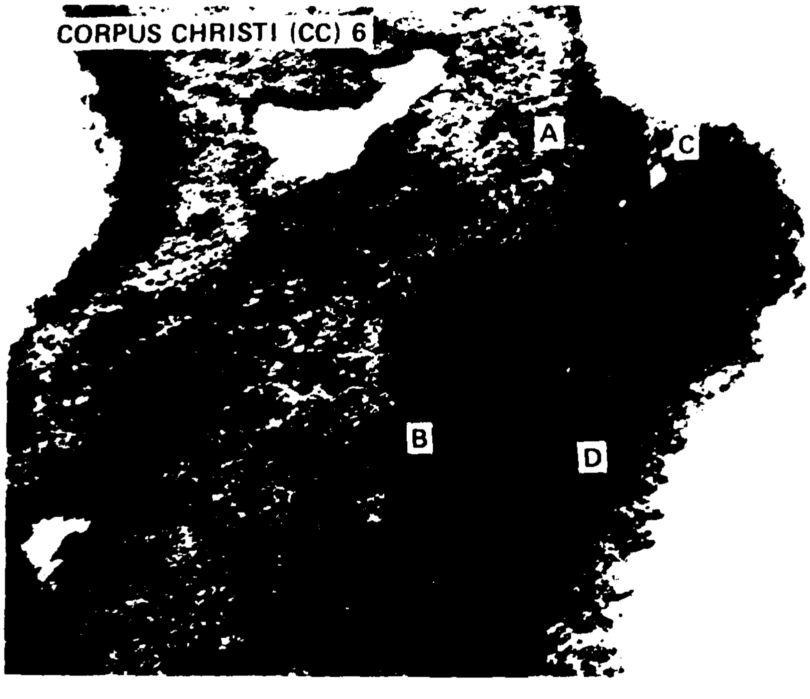


Photo 6. Site CC6

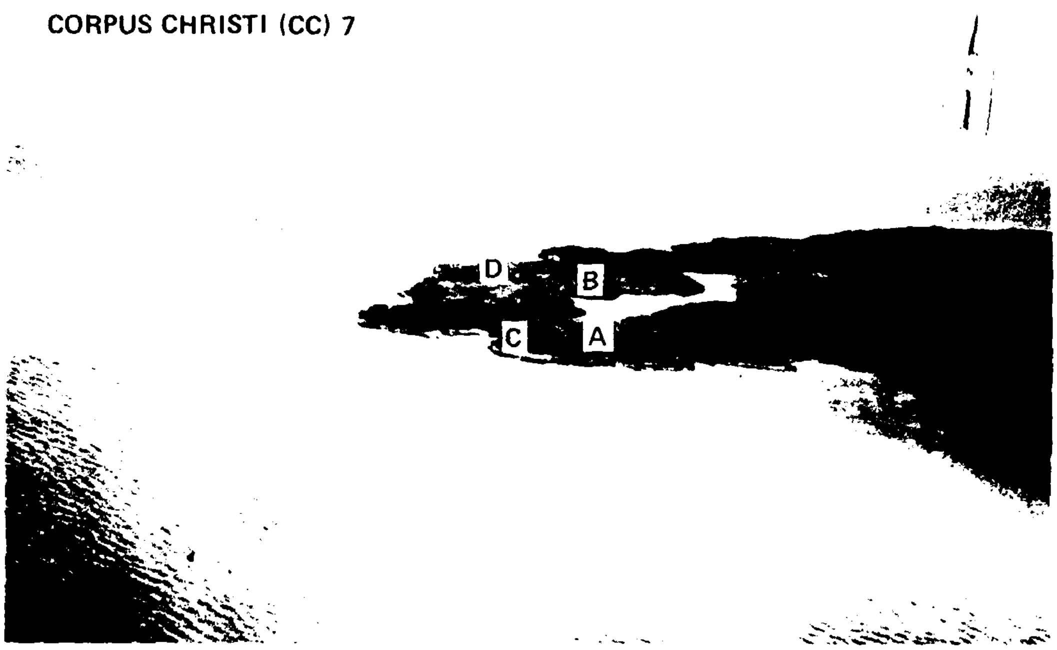


Photo 7. Site CC7

Photo 8. Site CC8

CORPUS CHRISTI (CC) 9

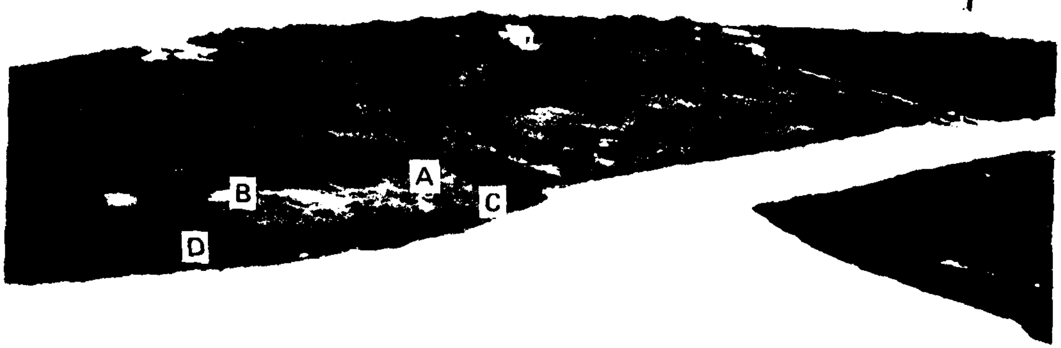


Photo 9. Site CC9

CORPUS CHRISTI (CC) 10

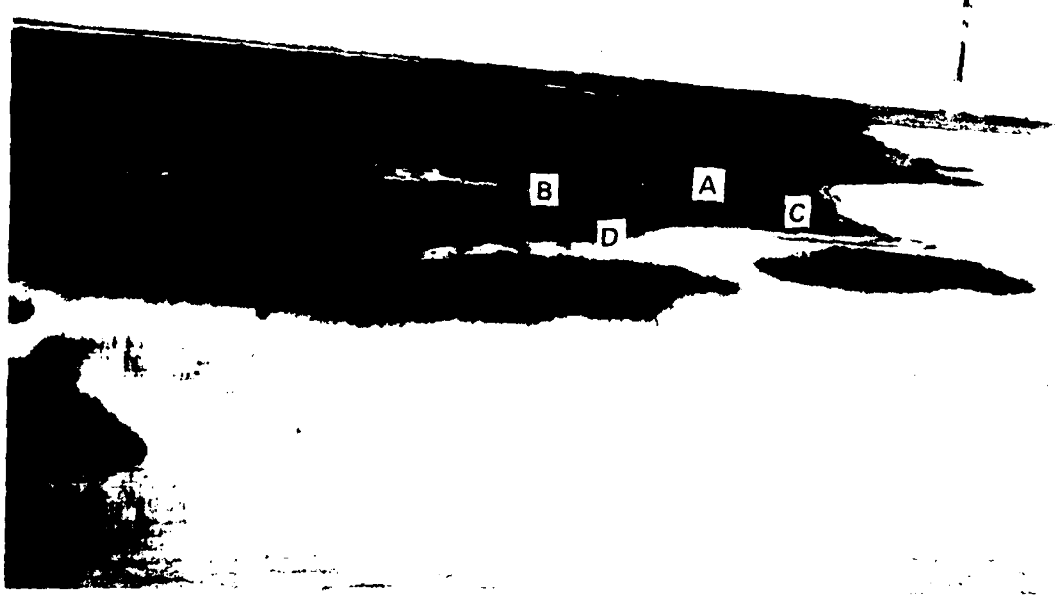


Photo 10. Site CC10

Photo 11. Site CC11

Photo 12. Site CC12

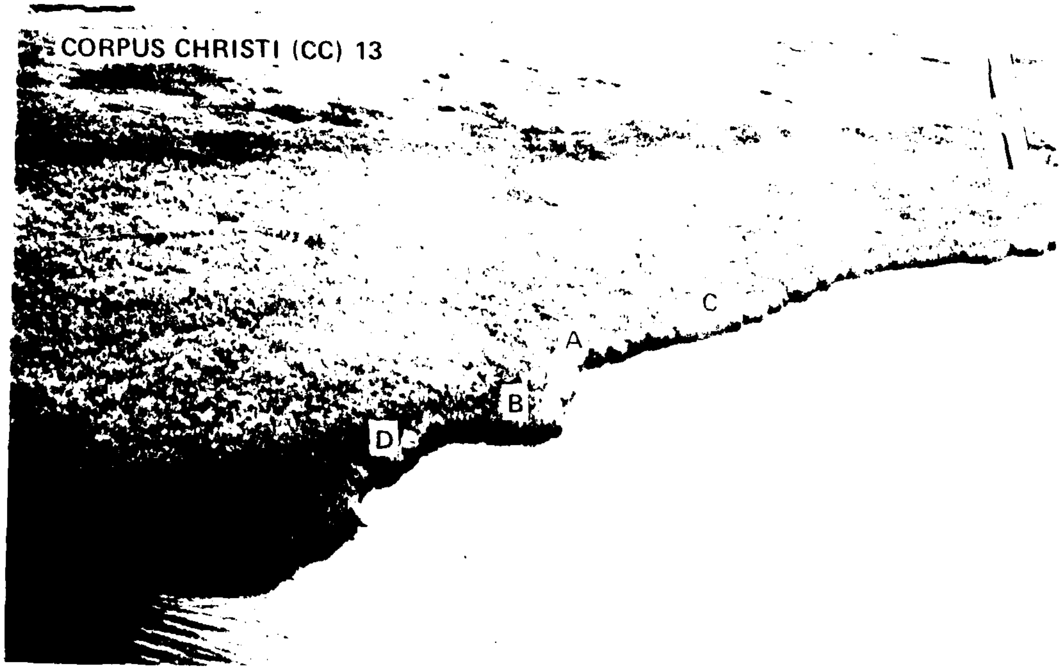


Photo 13. Site CC13

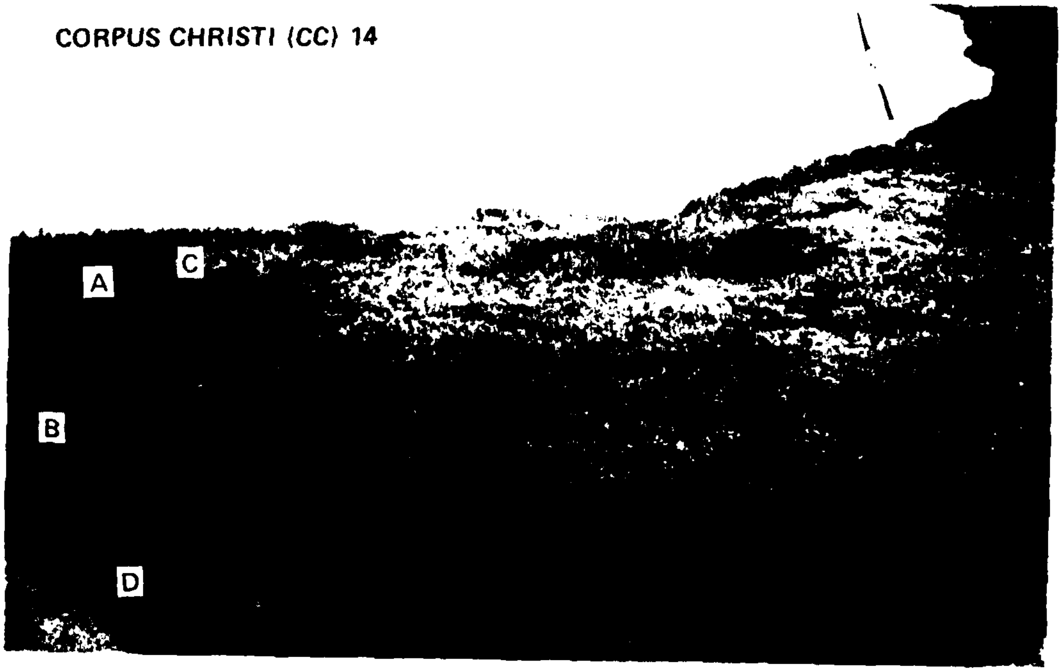


Photo 14. Site CC14

CORPUS CHRISTI (CC) 15

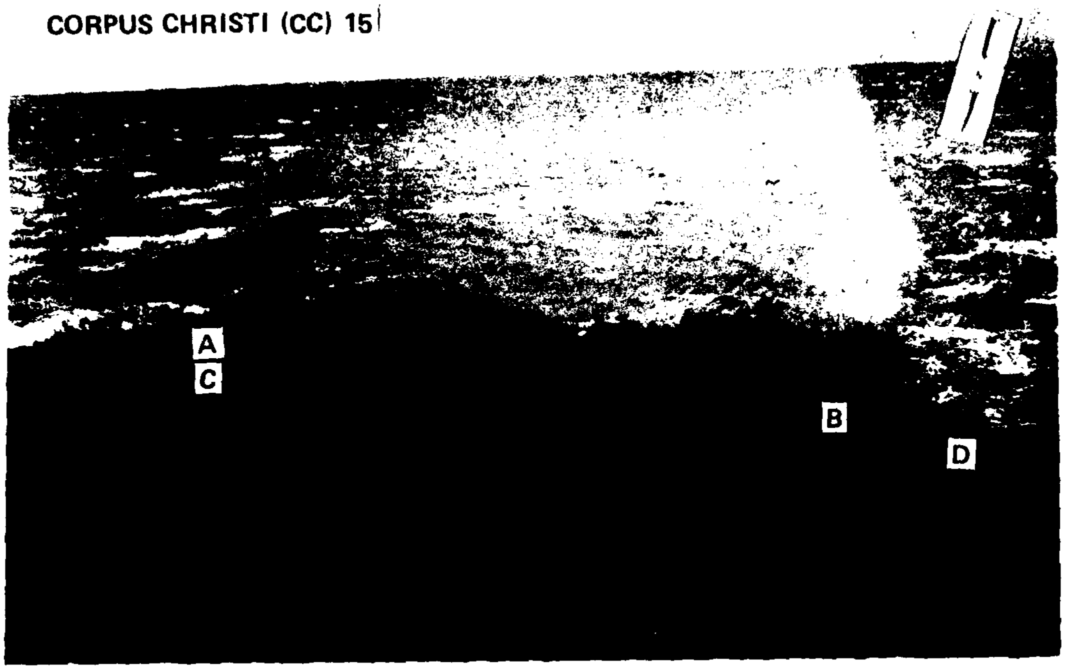


Photo 15. Site CC15

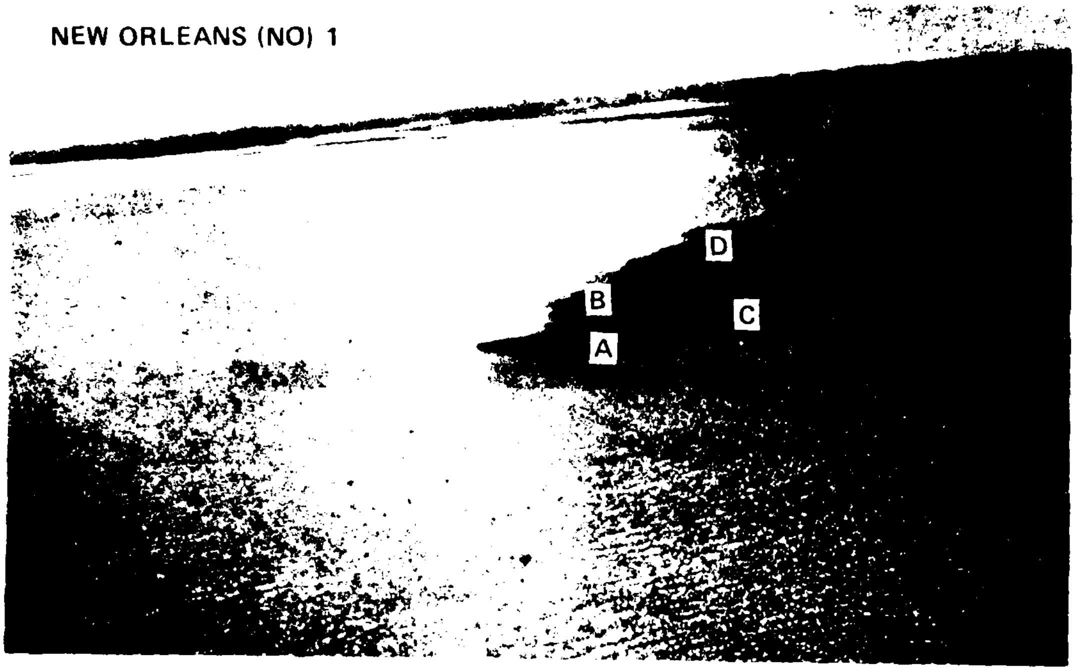


Photo 16. Site NO1

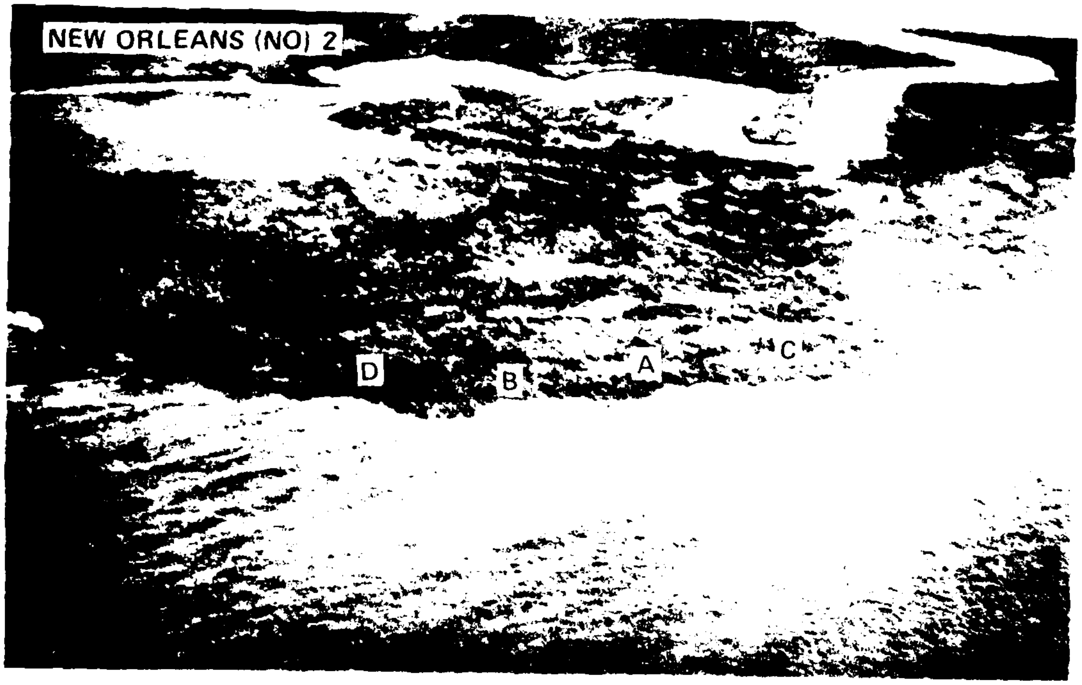


Photo 17. Site NO2

PHOTOS NOT AVAILABLE ON
NEW ORLEANS SITES 3, 4, AND 5

Photo 18. Sites NO3, NO4, and NO5

NEW ORLEANS (NO) 6

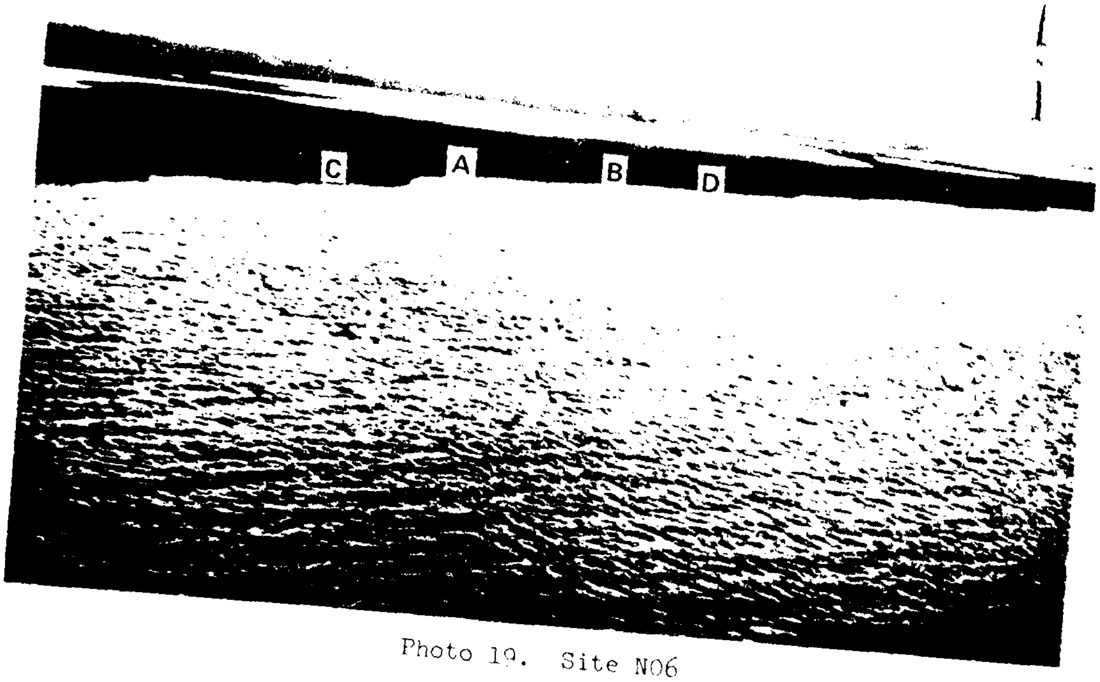
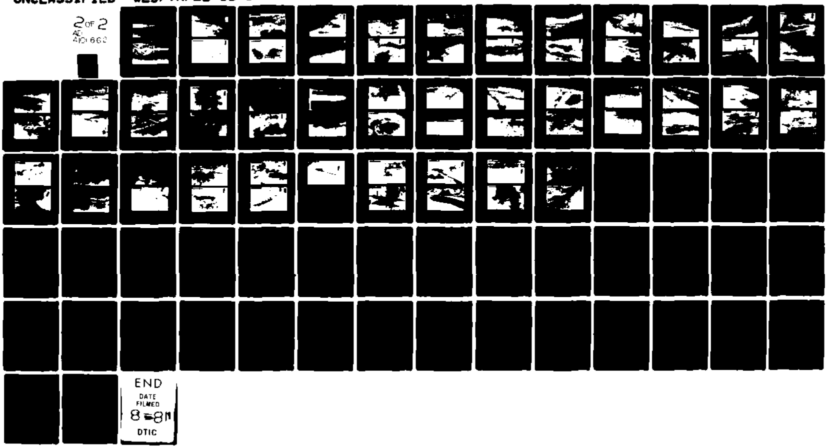


Photo 19. Site NO6

AD-A101 662 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 6/6
FIELD SURVEY OF HEAVY METAL UPTAKE BY NATURALLY OCCURRING SALTW--ETC(U)
JUN 81 J W SIMMERS, B L FOLSOM, C R LEE
UNCLASSIFIED WES/TR/EL-81-5 NL



NEW ORLEANS (NO) 7

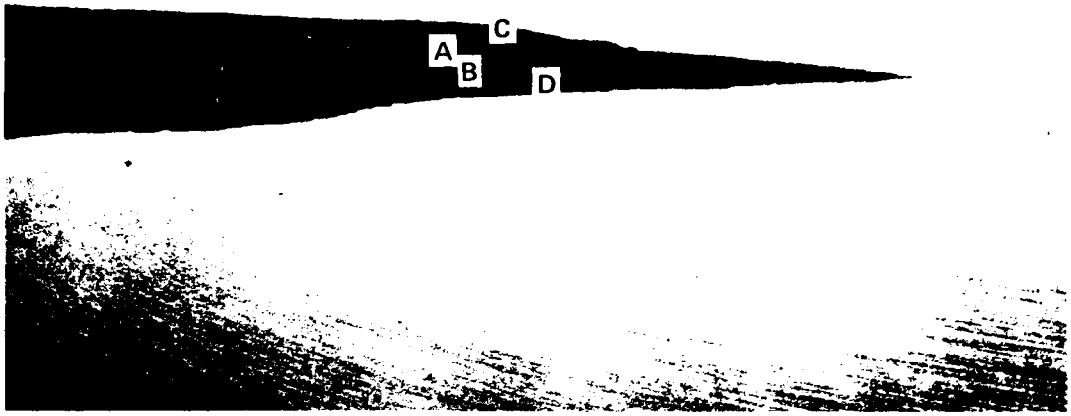


Photo 20. Site NO7

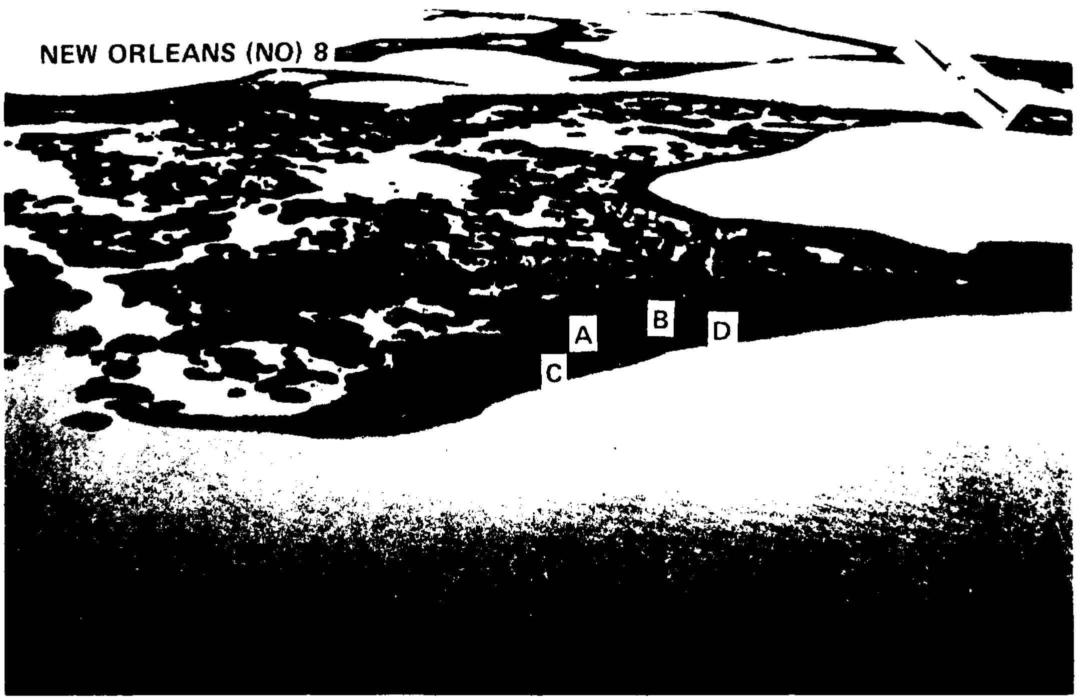


Photo 21. Site NO8

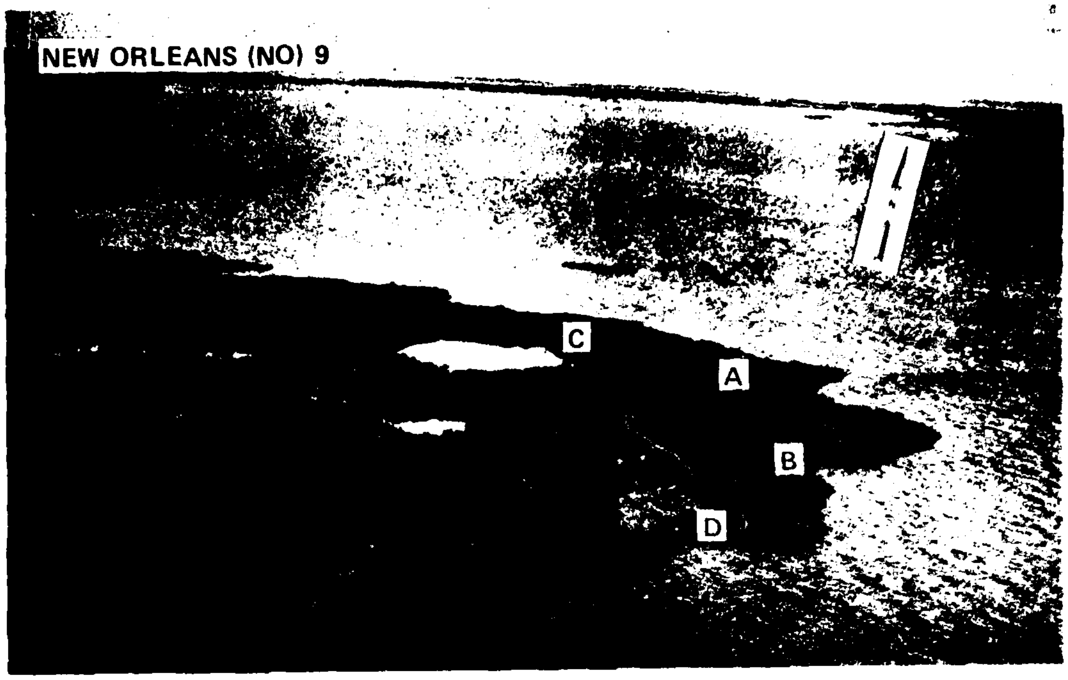


Photo 22. Site NO9

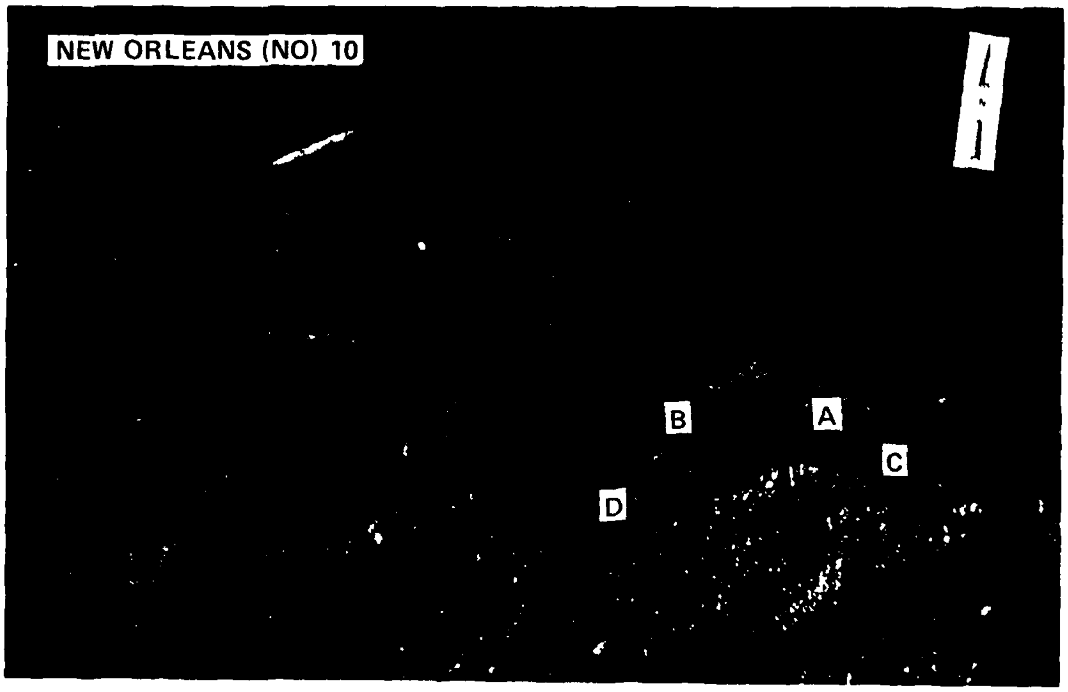


Photo 23. Site NO10

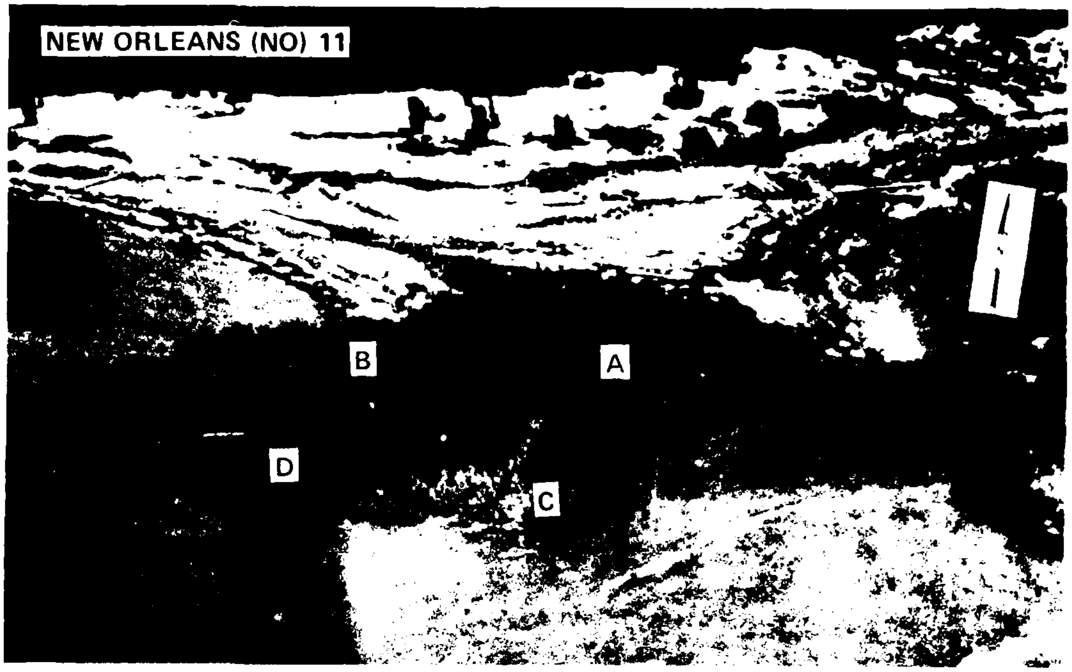


Photo 24. Site NO11

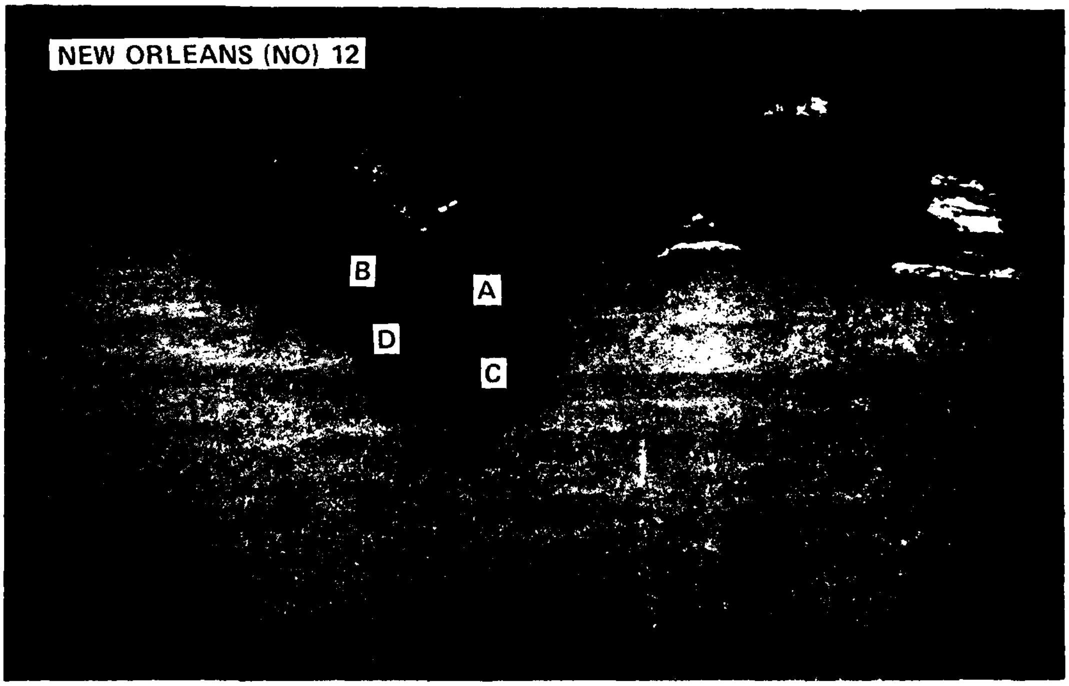


Photo 25. Site NO12

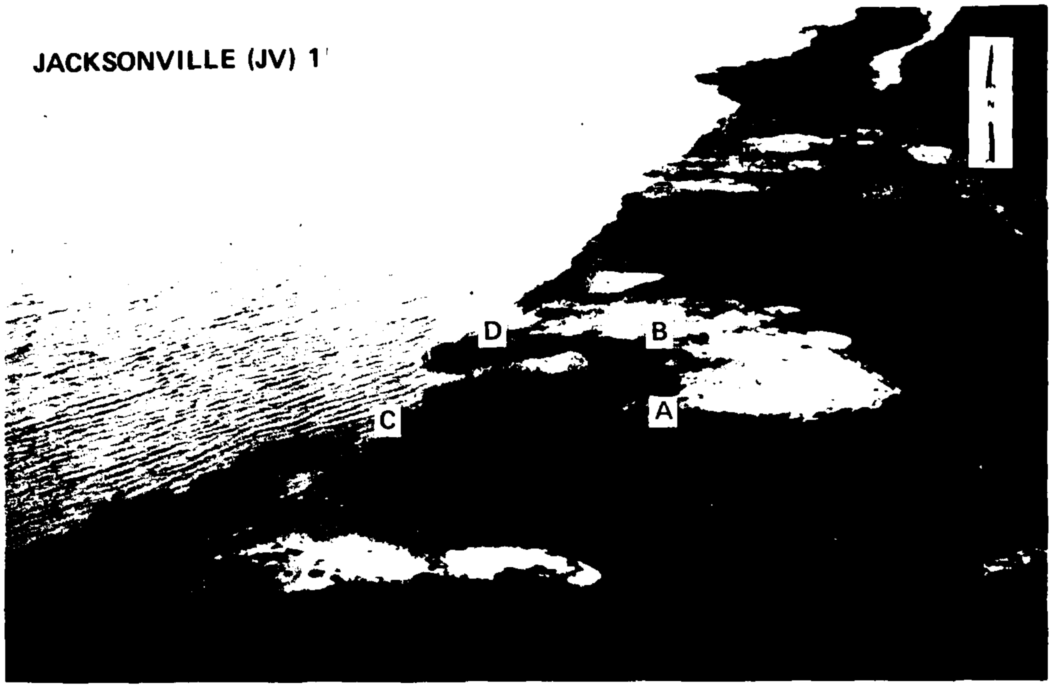


Photo 26. Site JV1

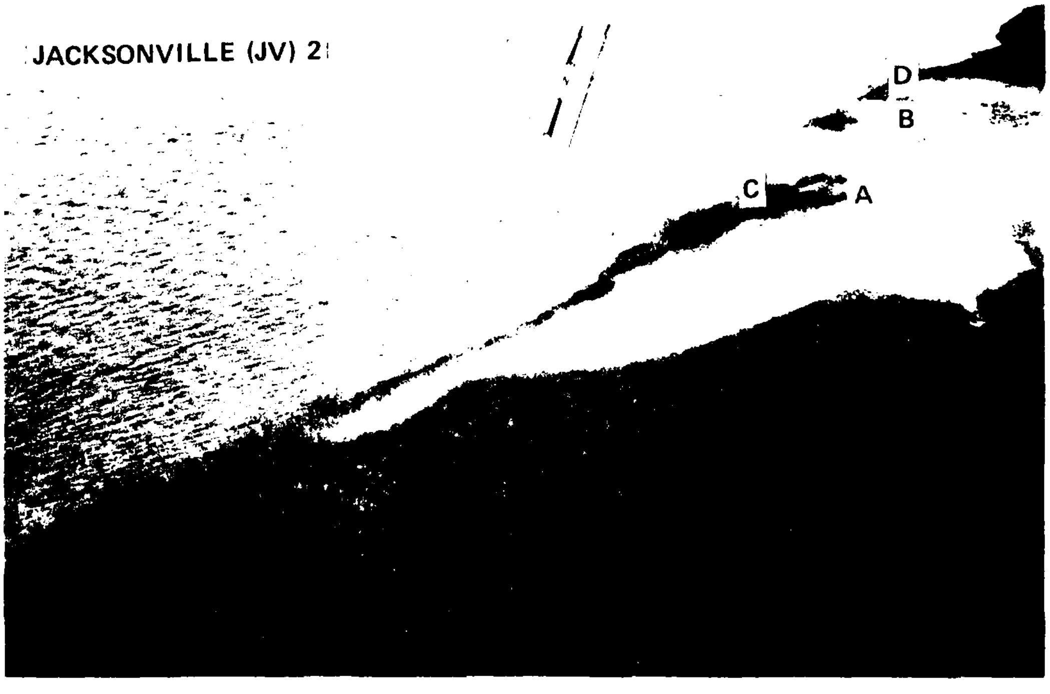


Photo 27. Site JV2

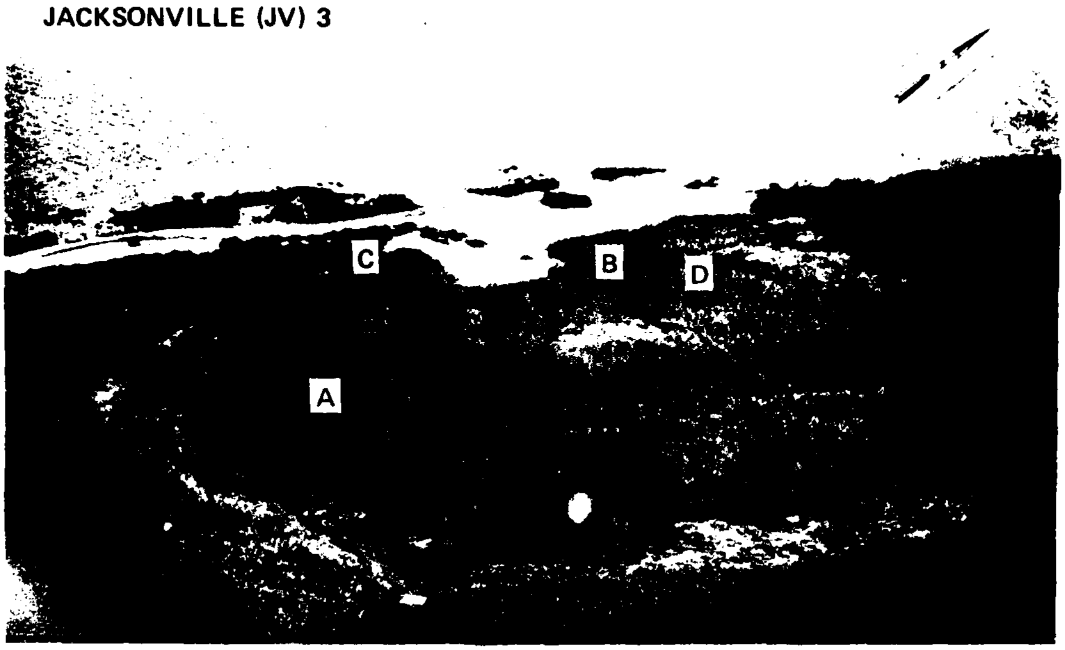


Photo 28. Site JV3

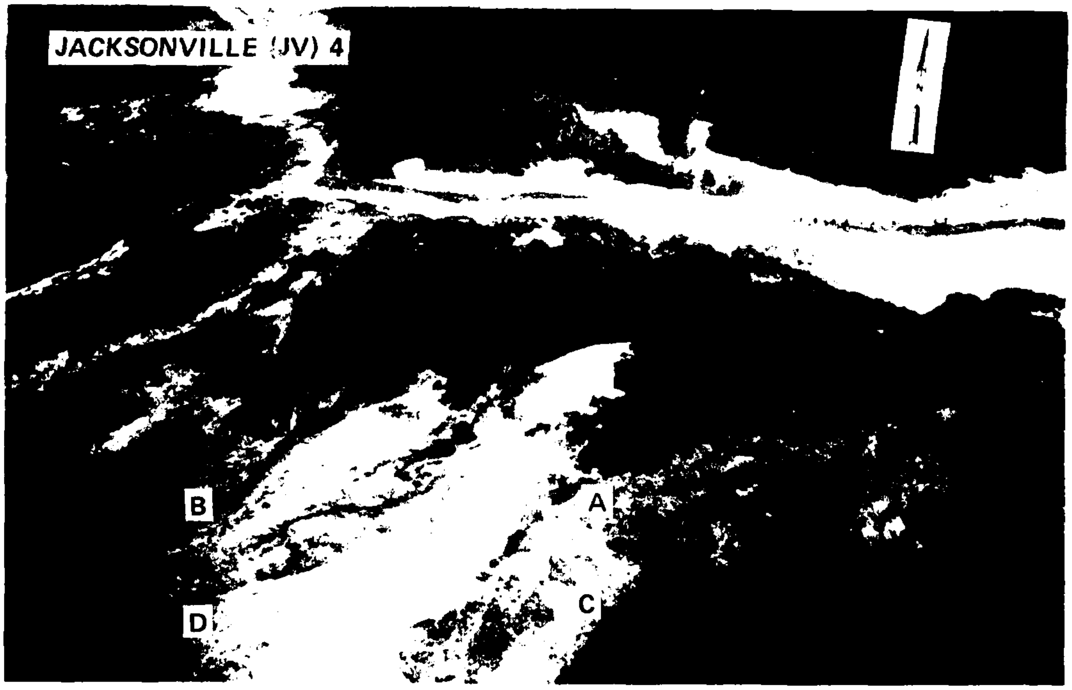


Photo 29. Site JV4

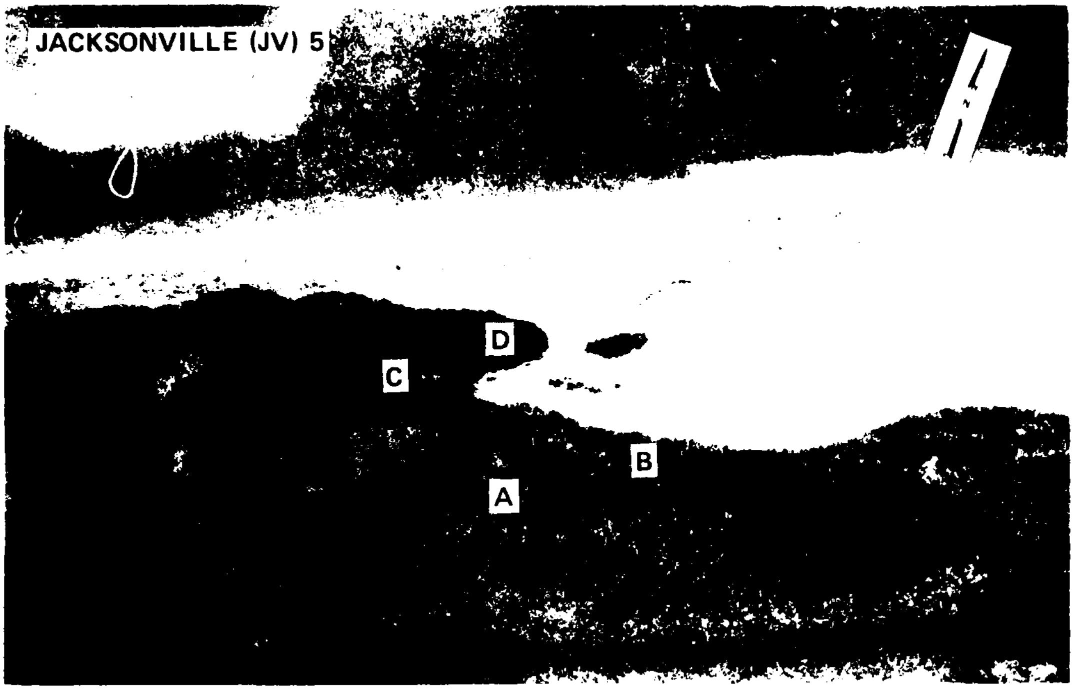


Photo 30. Site JV5

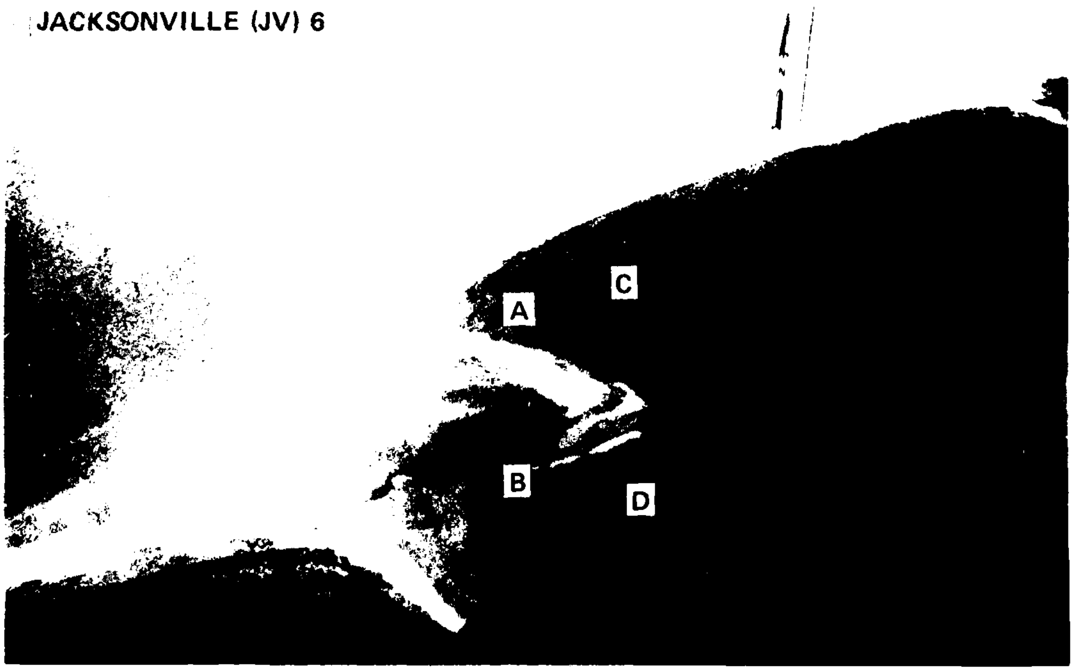


Photo 31. Site JV6

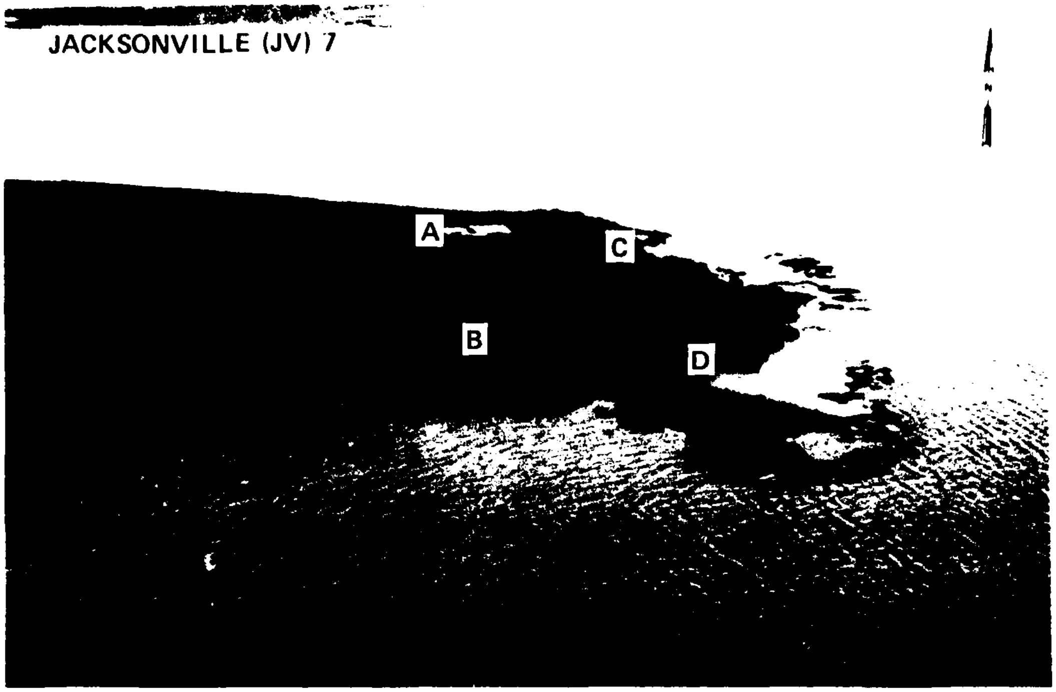


Photo 32. Site JV7

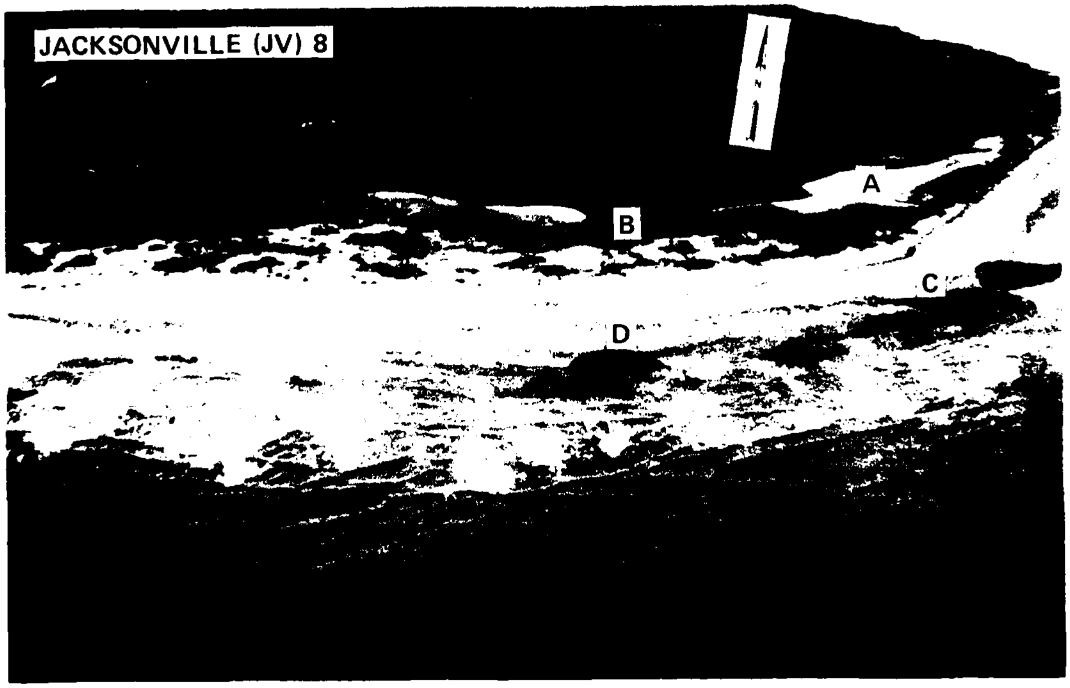


Photo 33. Site JV8

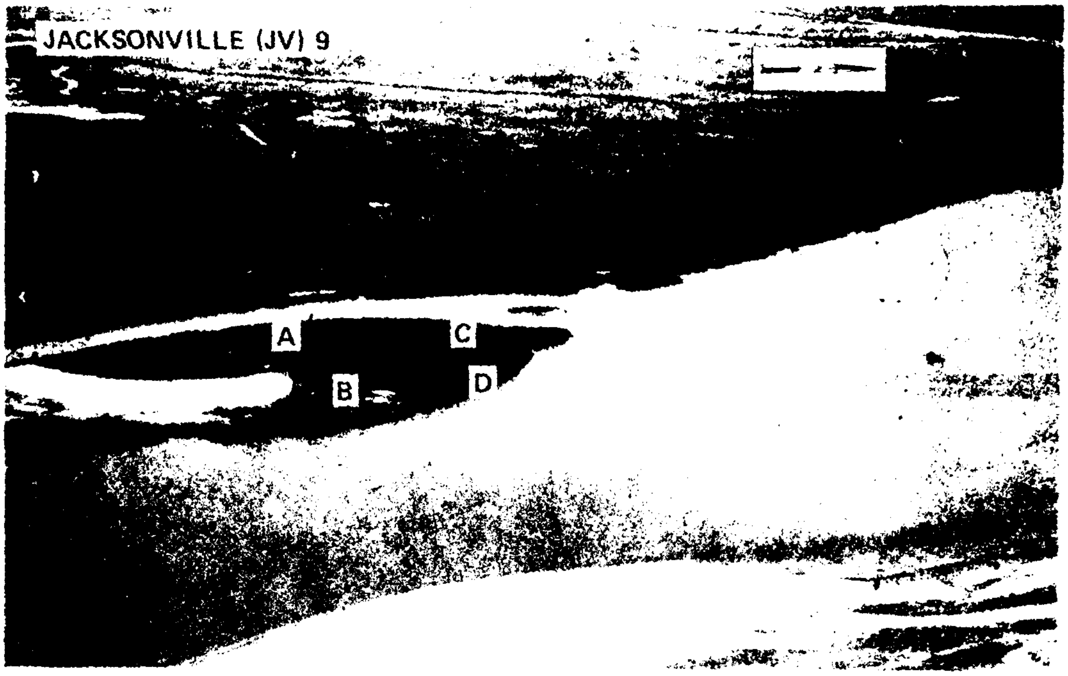


Photo 34. Site JV9

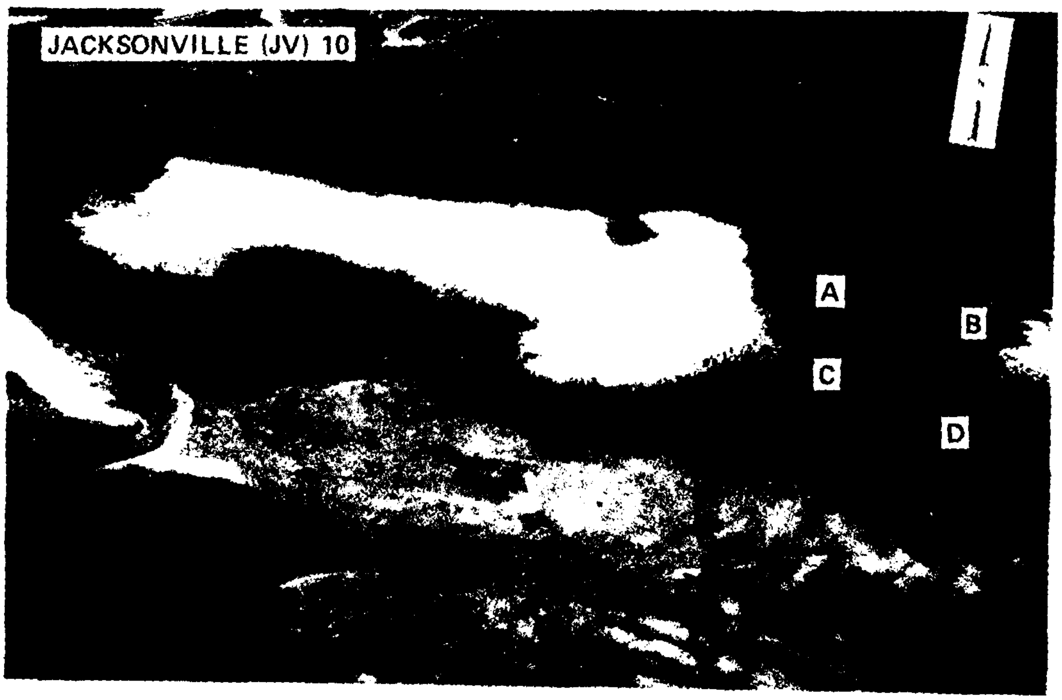


Photo 35. Site JV10

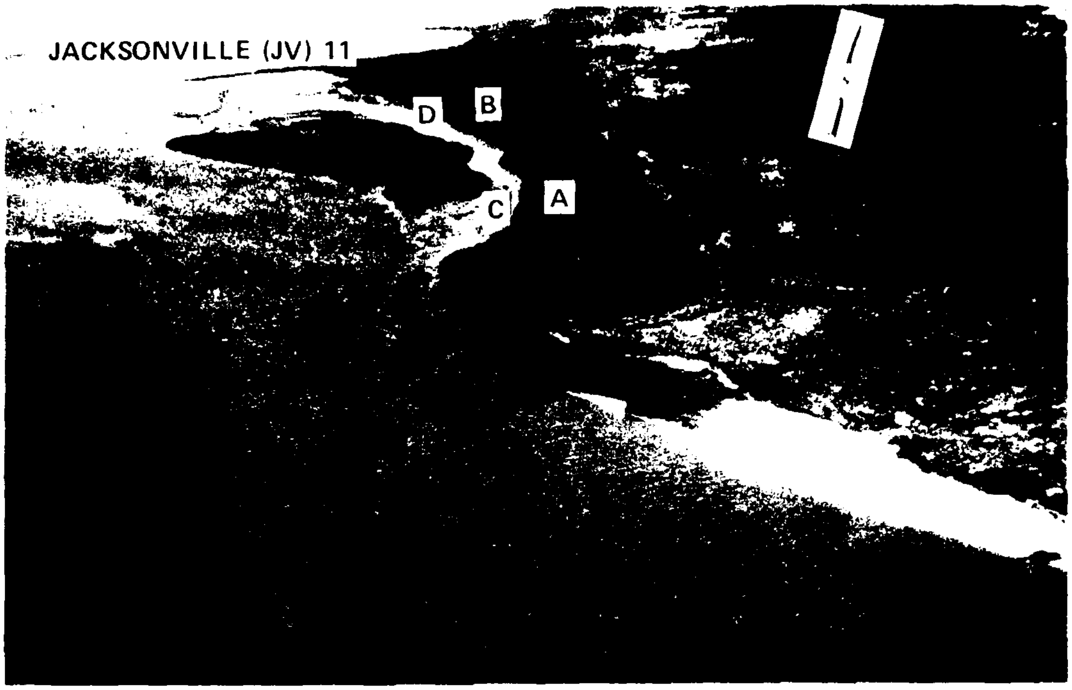


Photo 36. Site JV11

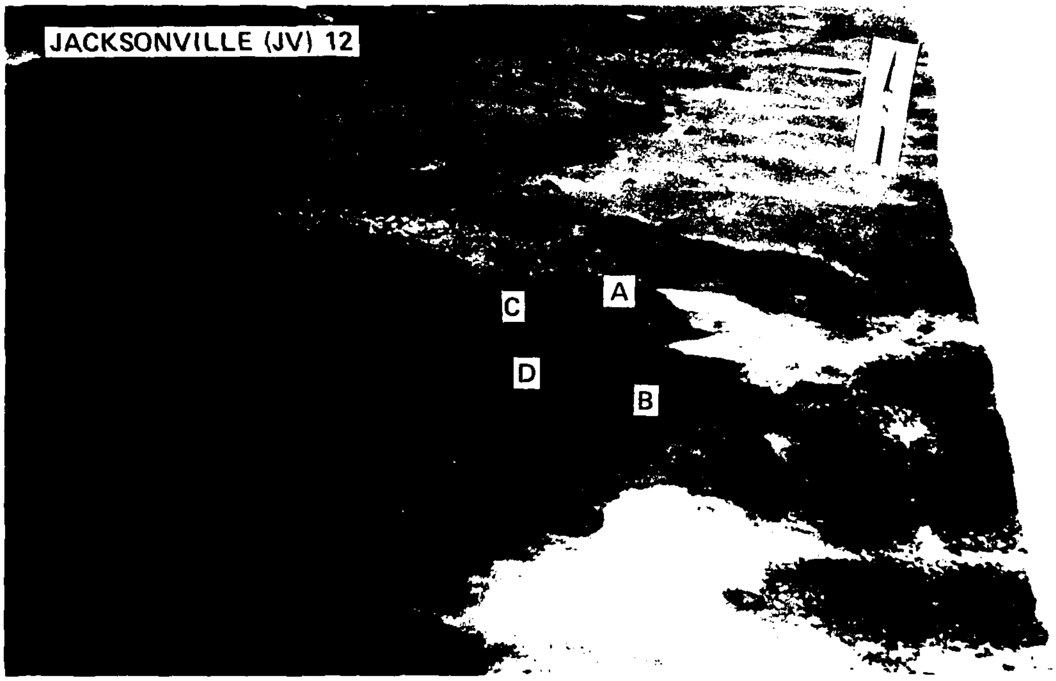


Photo 37. Site JV12

NEW YORK (NY) 1

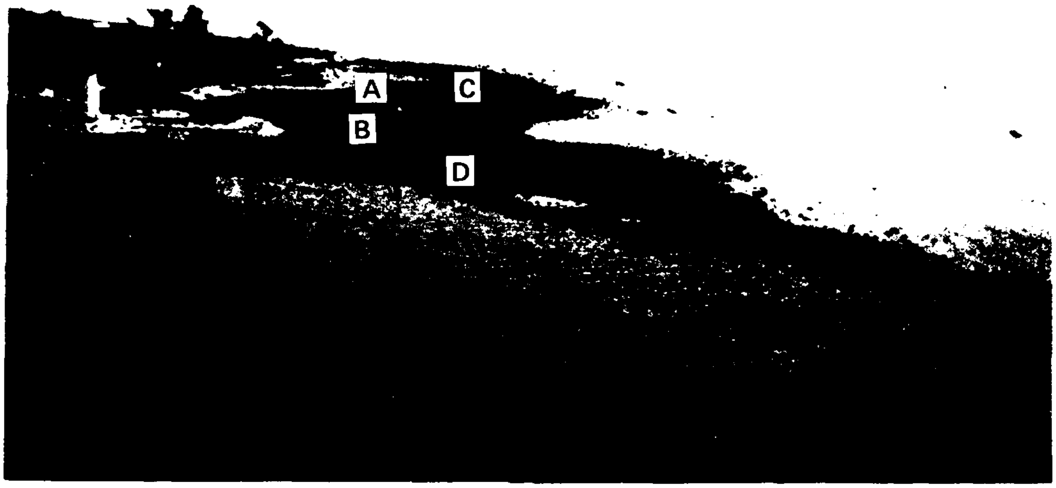


Photo 38. Site NY1

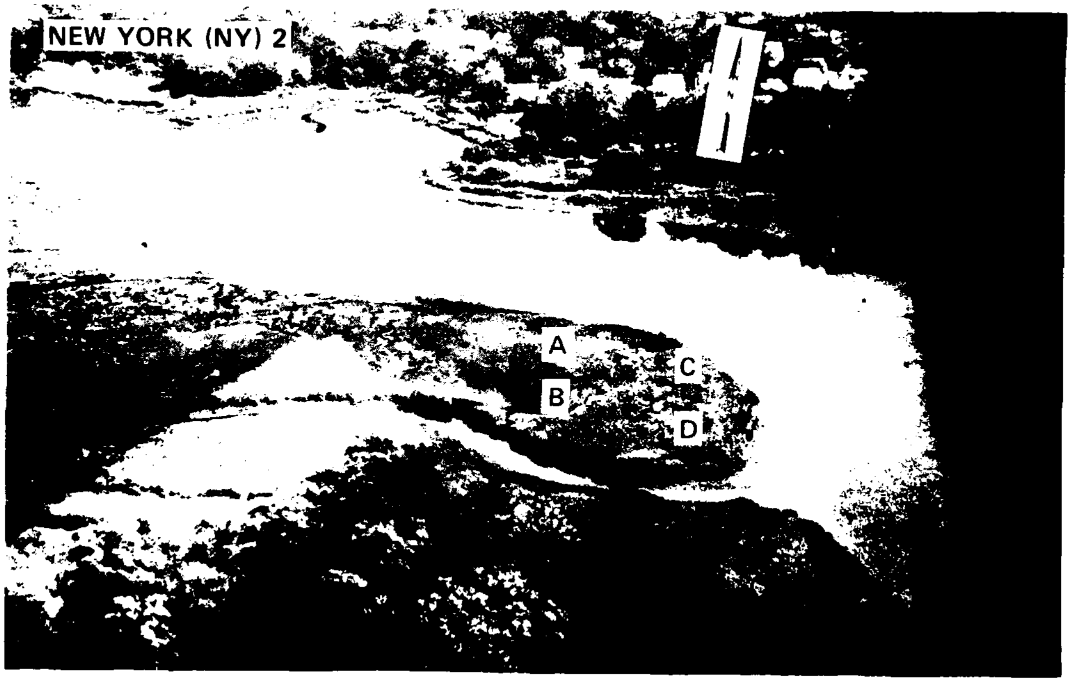


Photo 39. Site NY2

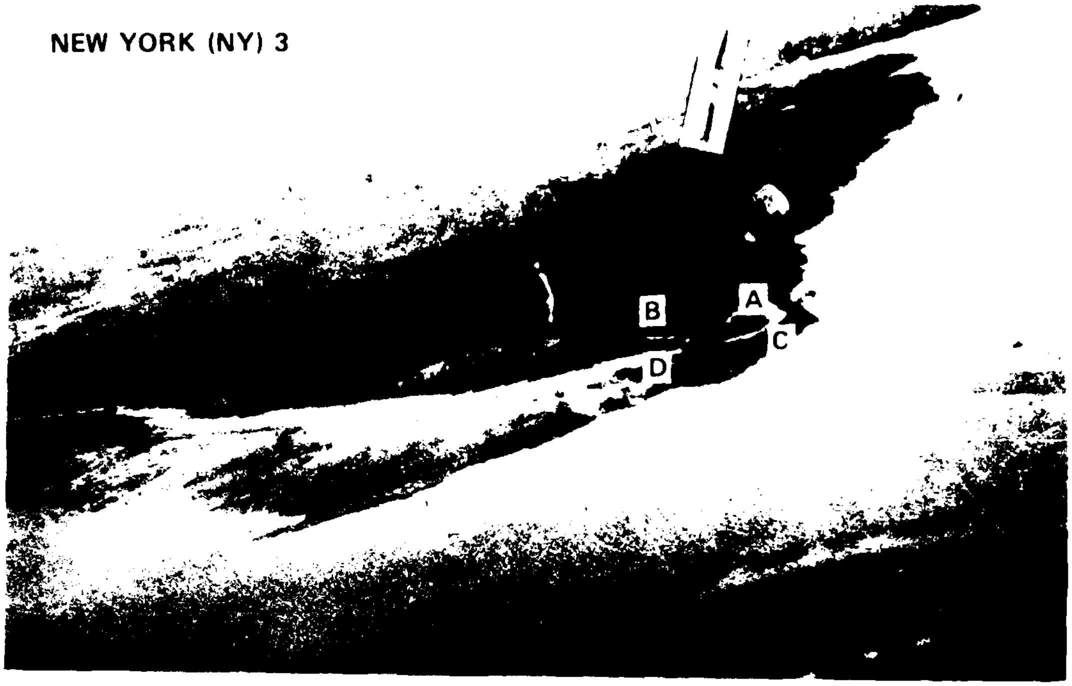


Photo 40. Site NY3

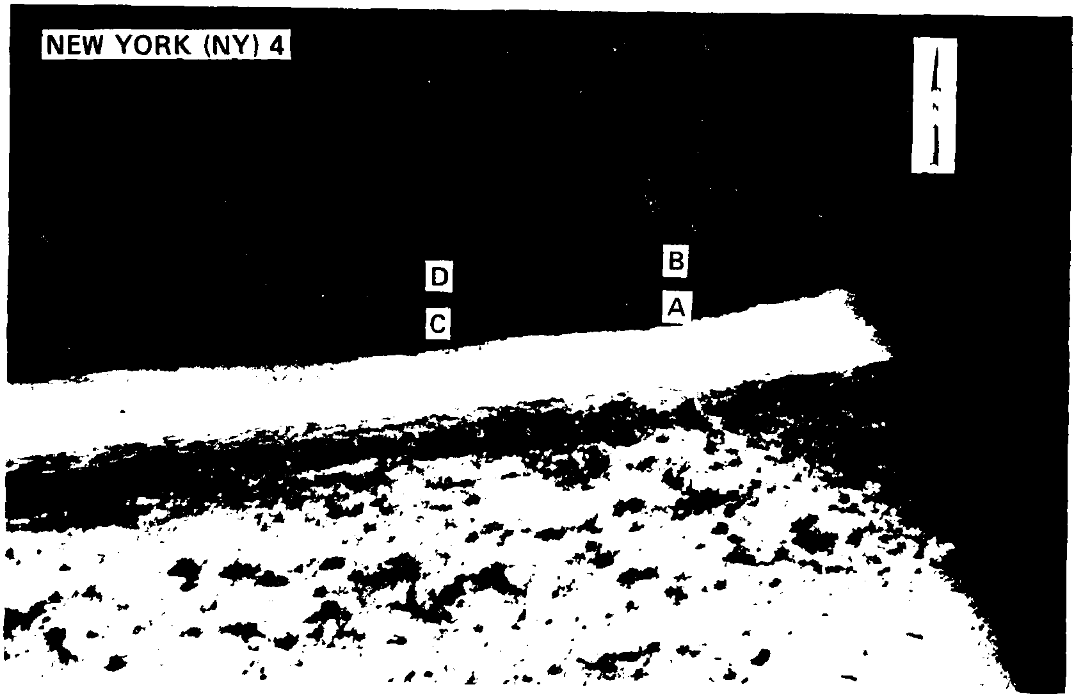


Photo 41. Site NY4

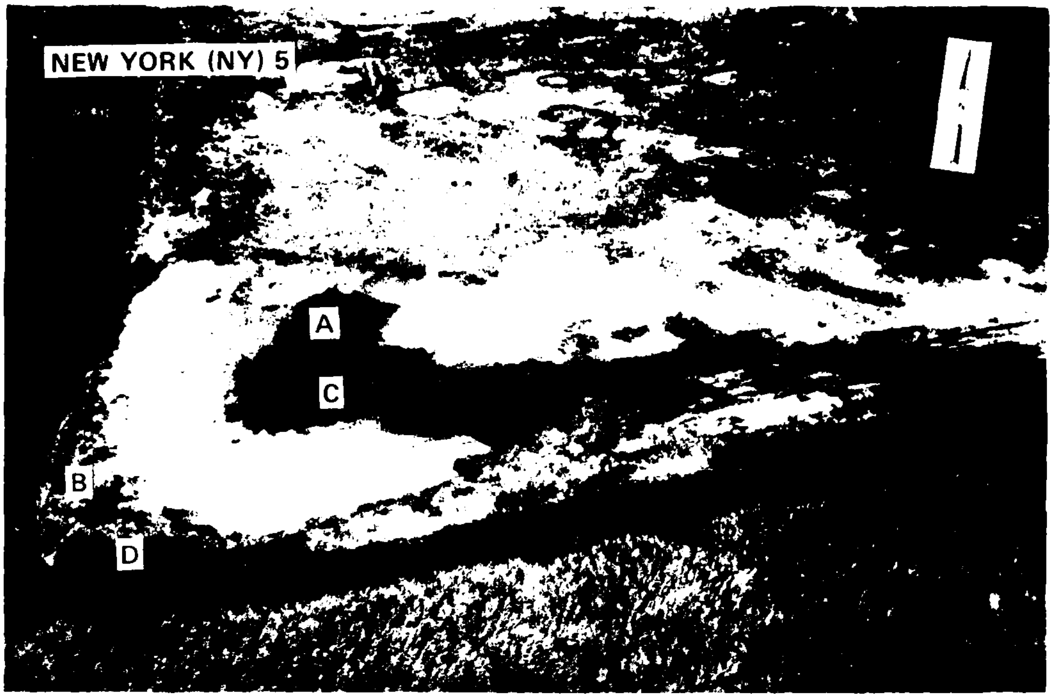


Photo 42. Site NY5

Photo 43. Site NY6

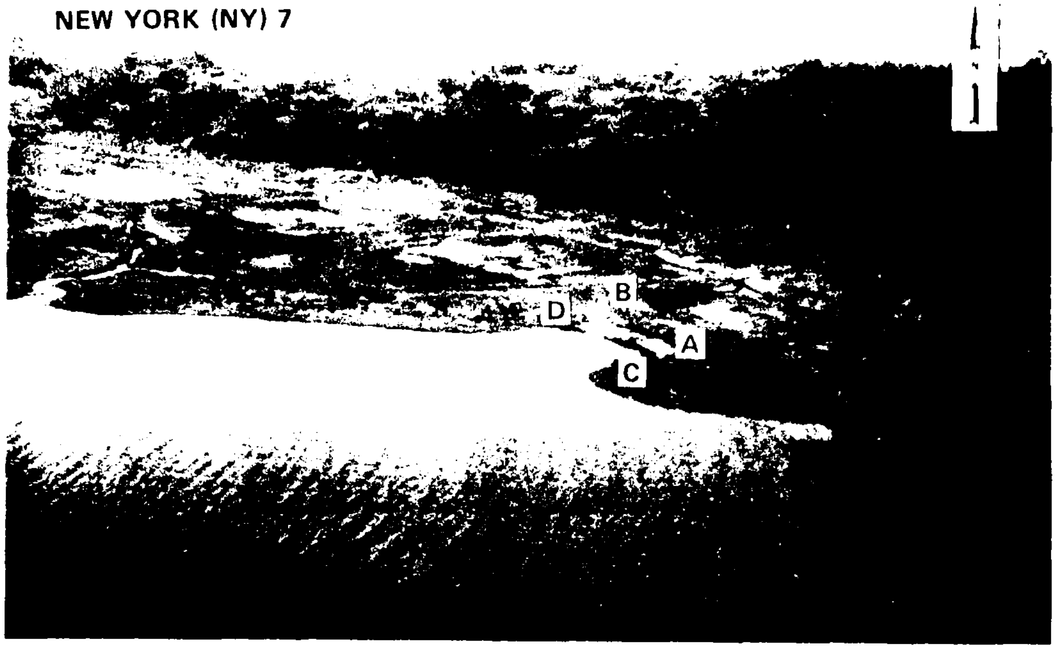


Photo 44. Site NY7

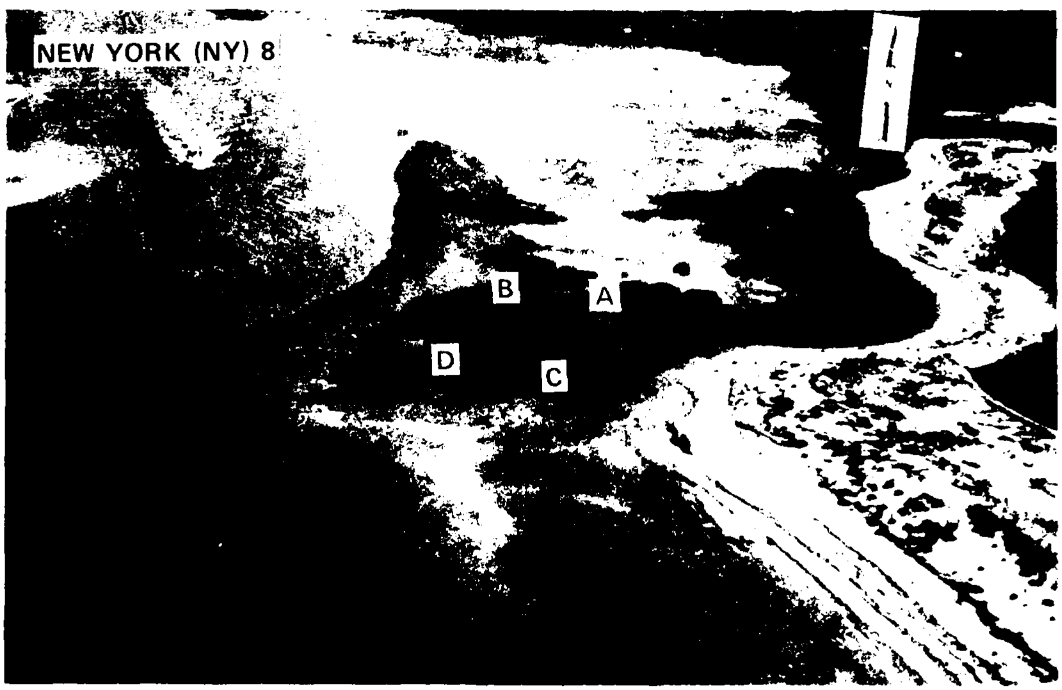


Photo 46. Site NY9

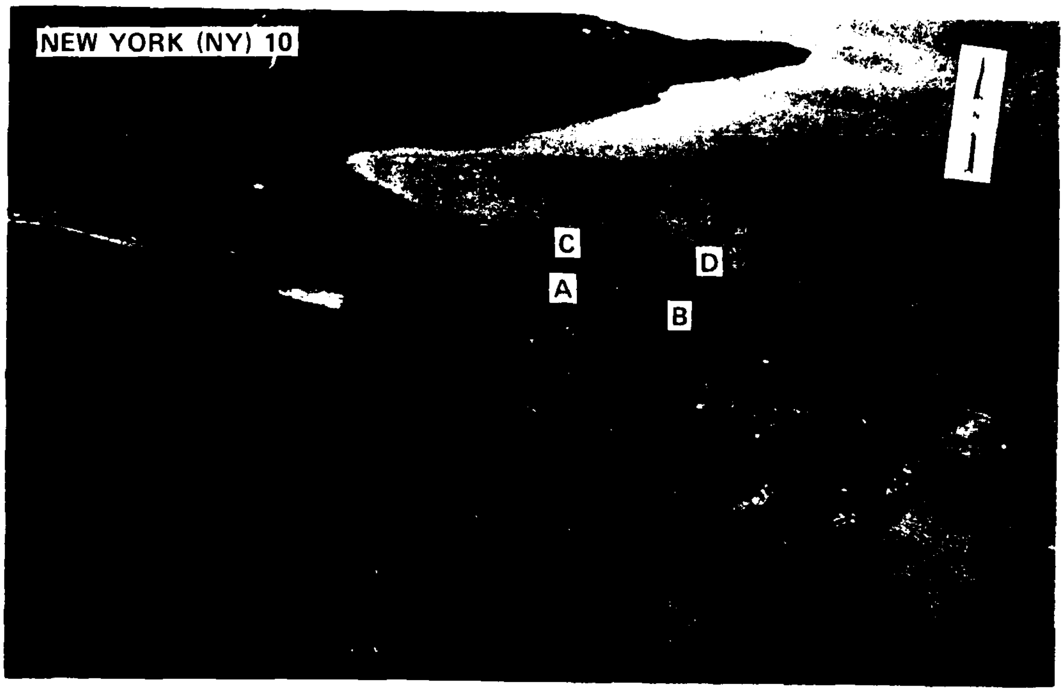


Photo 47. Site NY10

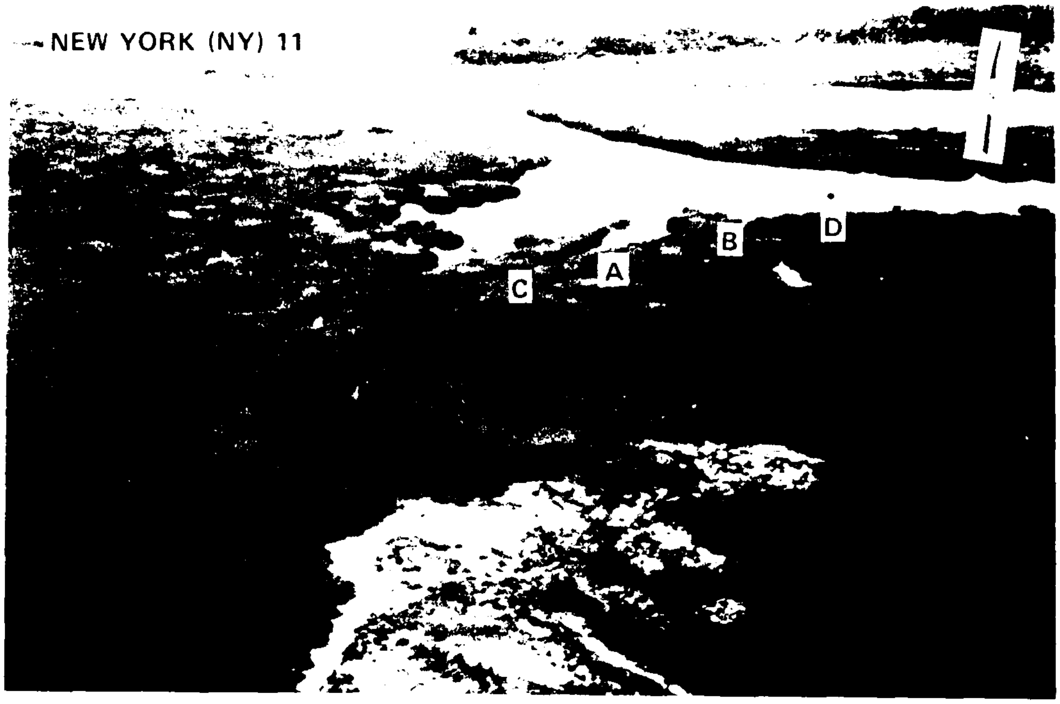


Photo 48. Site NY11

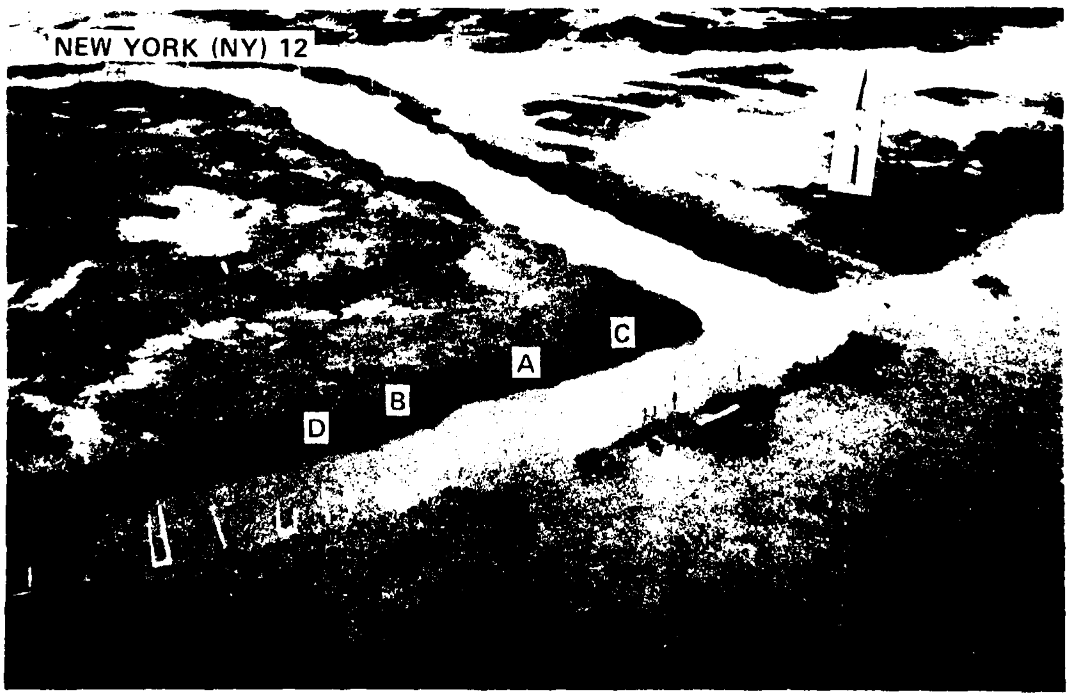


Photo 49. Site NY12

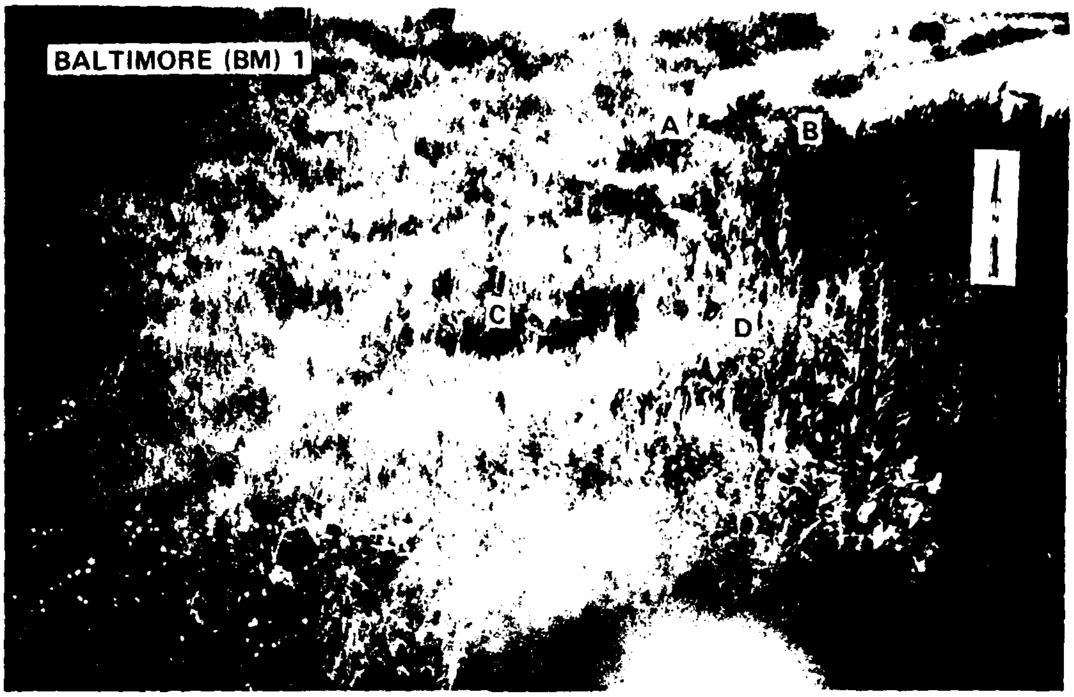


Photo 50. Site BM1

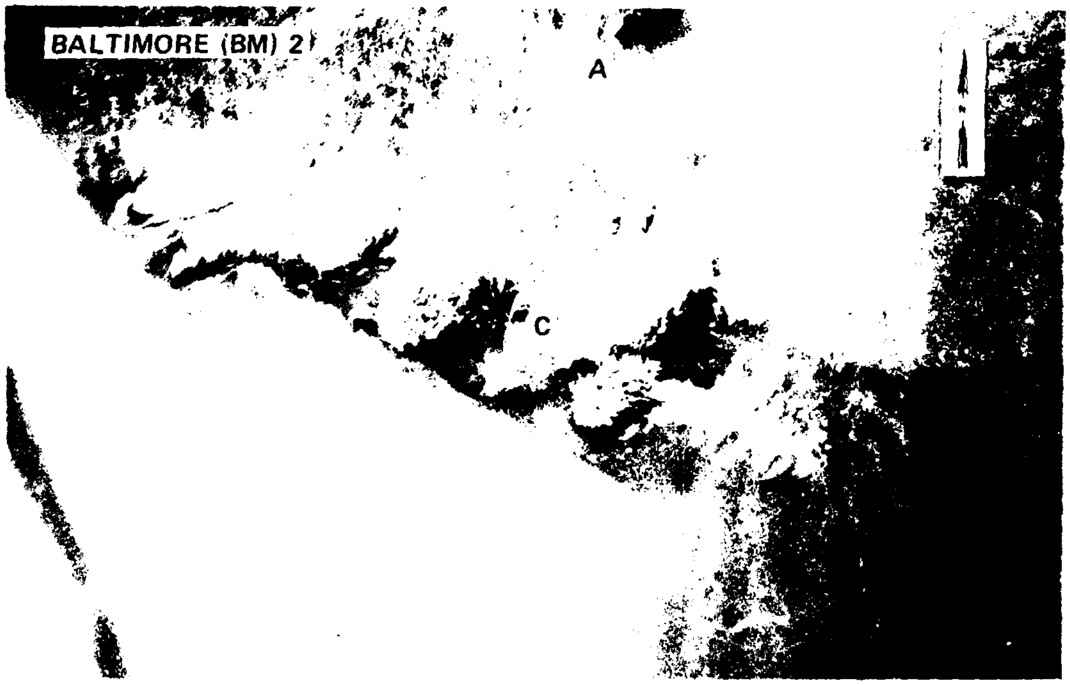


Photo 51. Site BM2

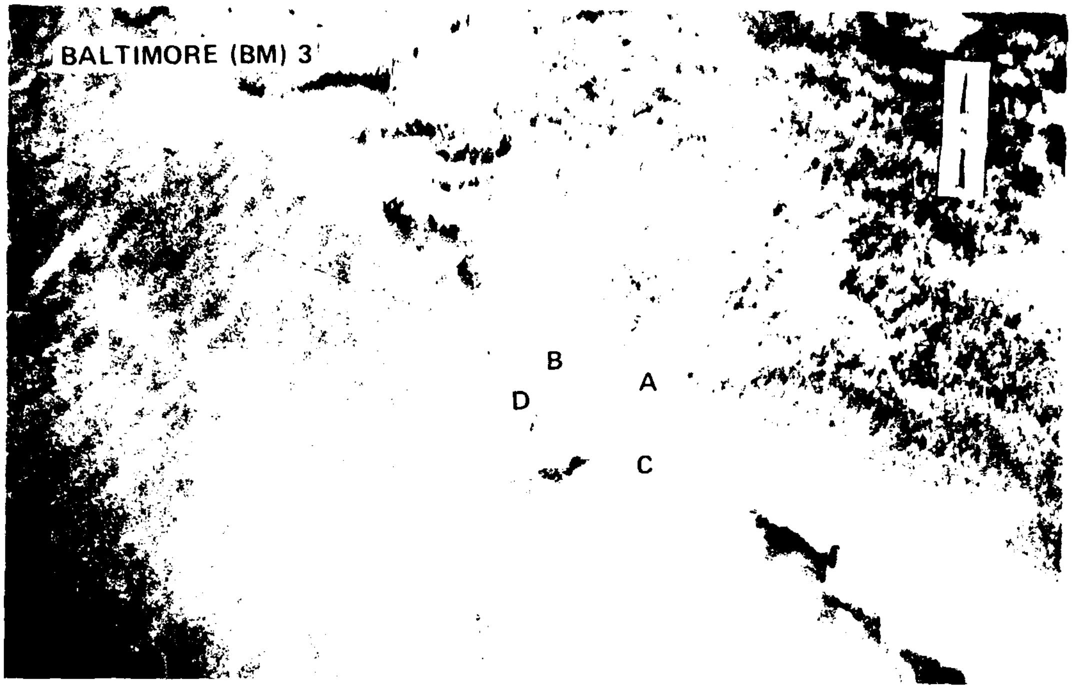


Photo 52. Site BM3

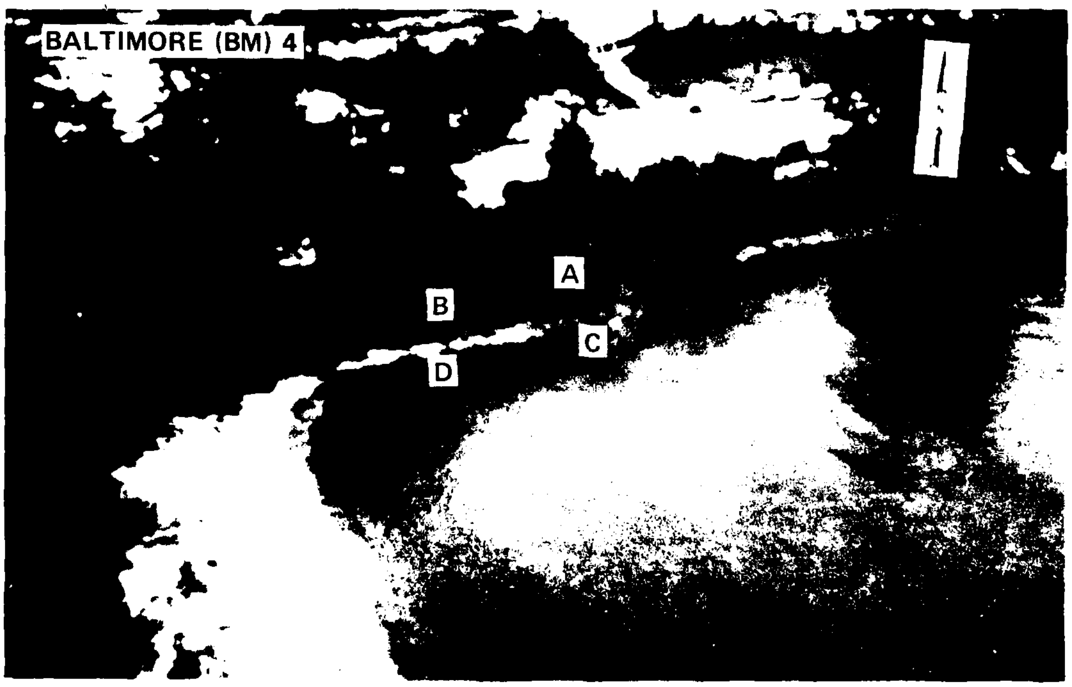


Photo 53. Site BM4

BALTIMORE (BM) 5

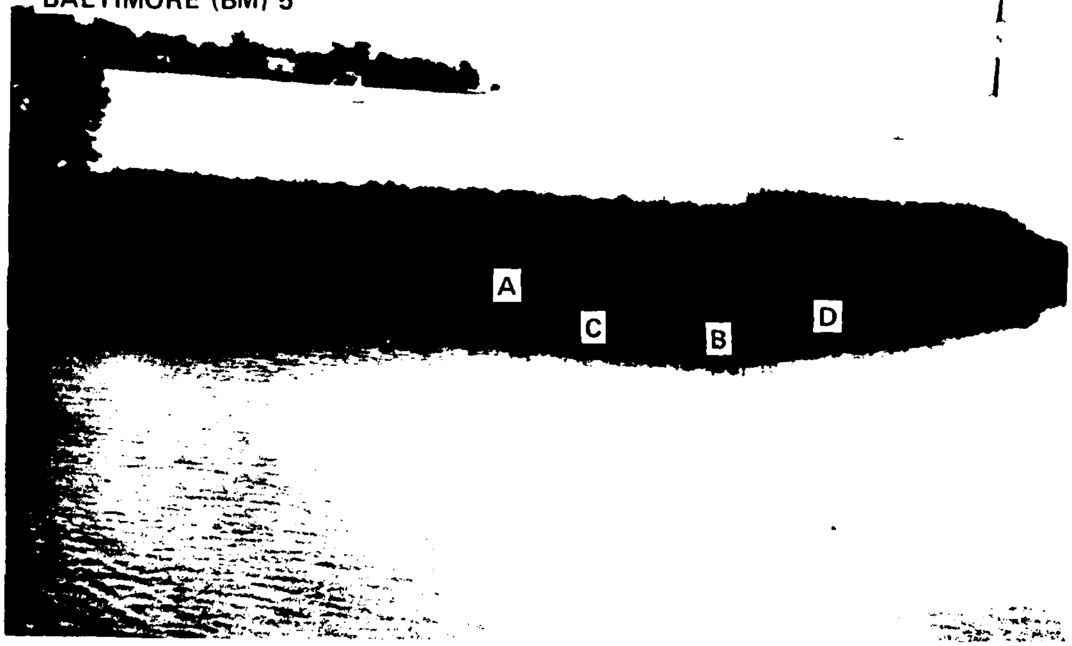


Photo 54. Site BM5

BALTIMORE (BM) 6

Photo 55. Site BM6

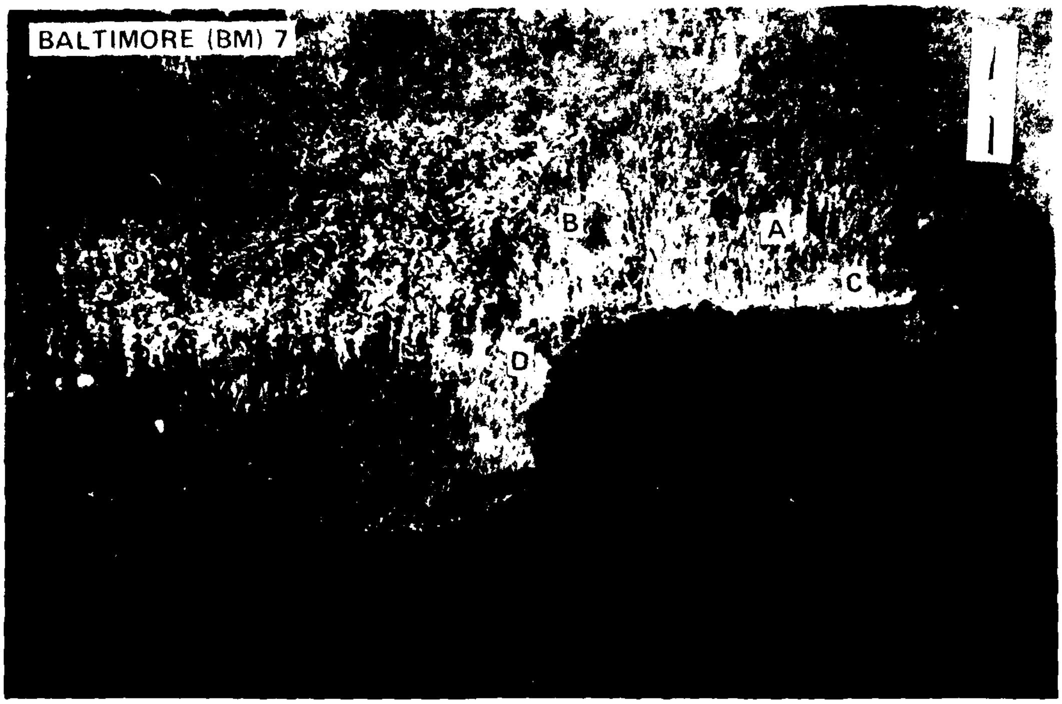


Photo 56. Photo BM7

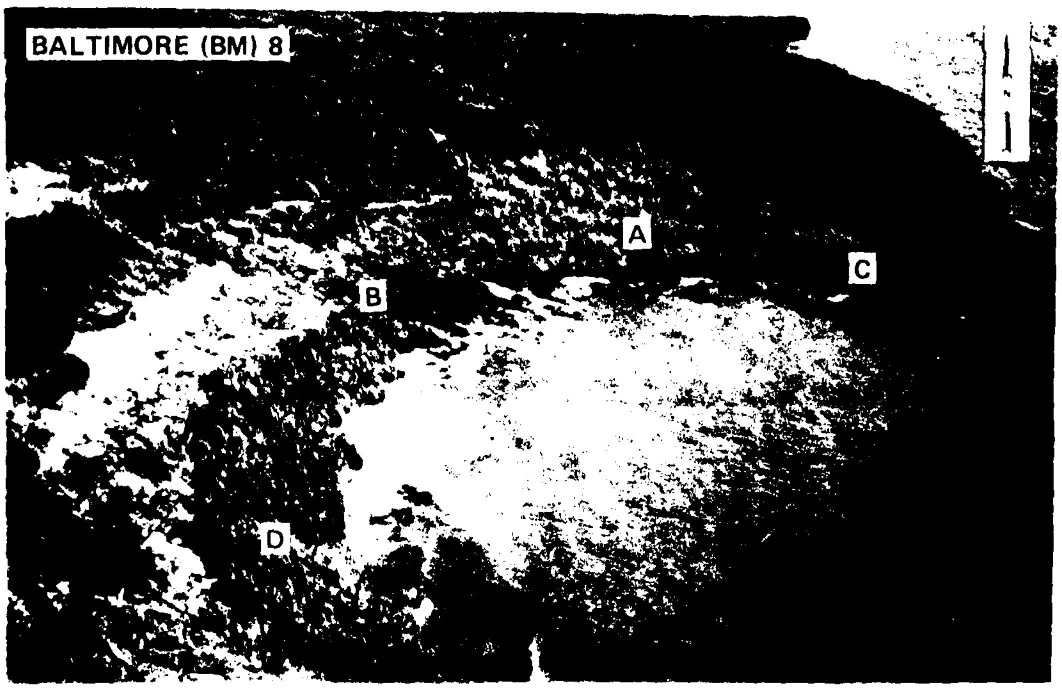


Photo 57. Site BM8

BALTIMORE (BM) 9

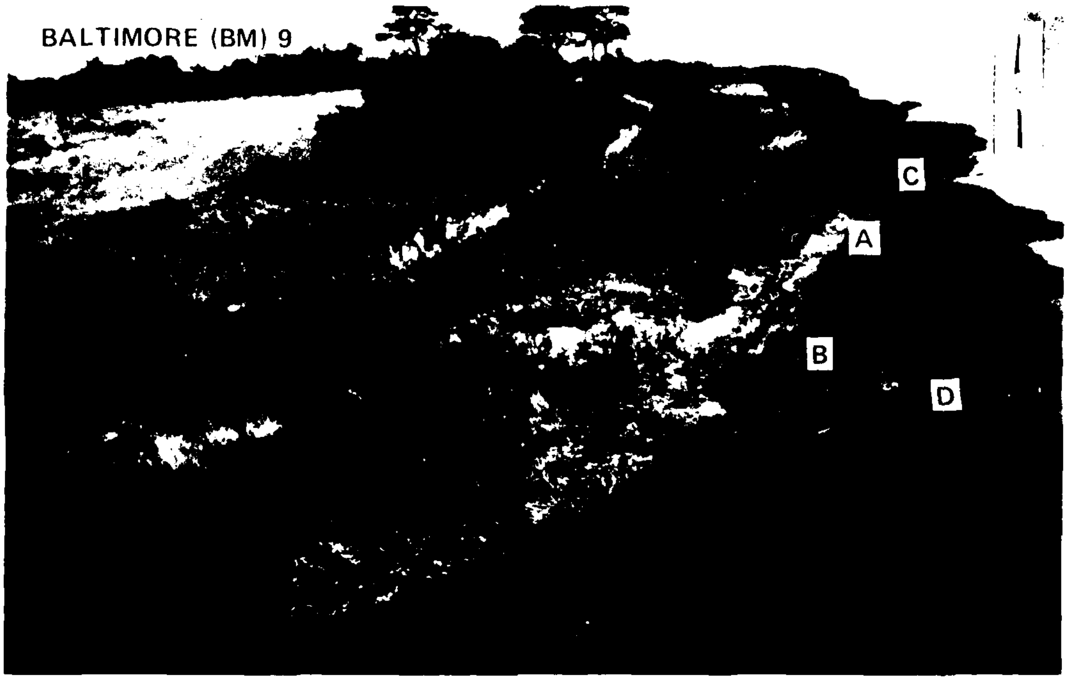


Photo 58. Site BM9

BALTIMORE (BM) 10

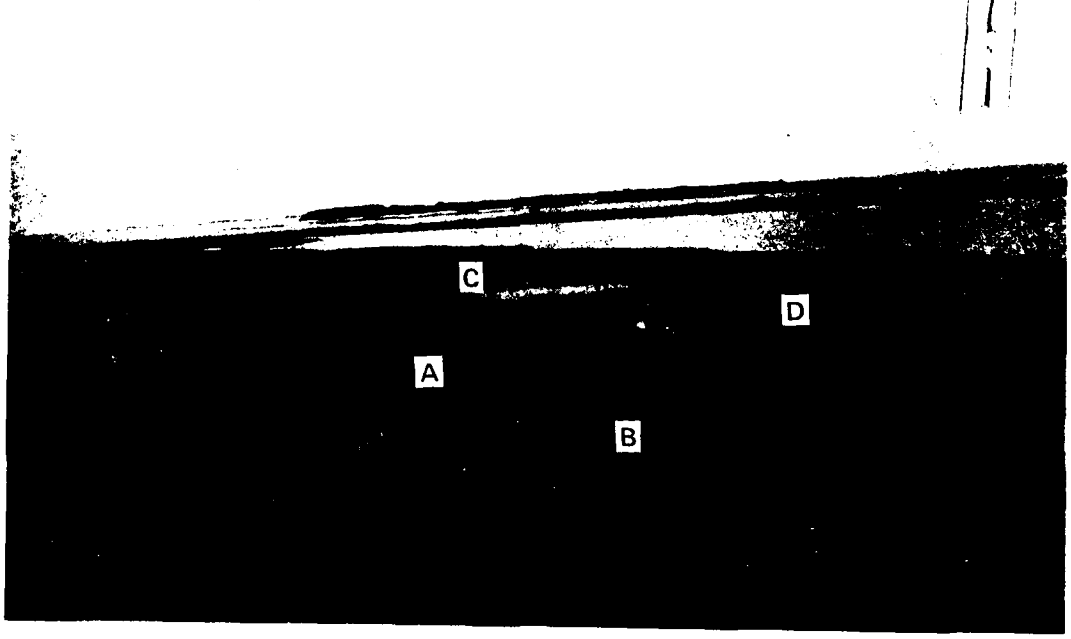


Photo 59. Site BM10

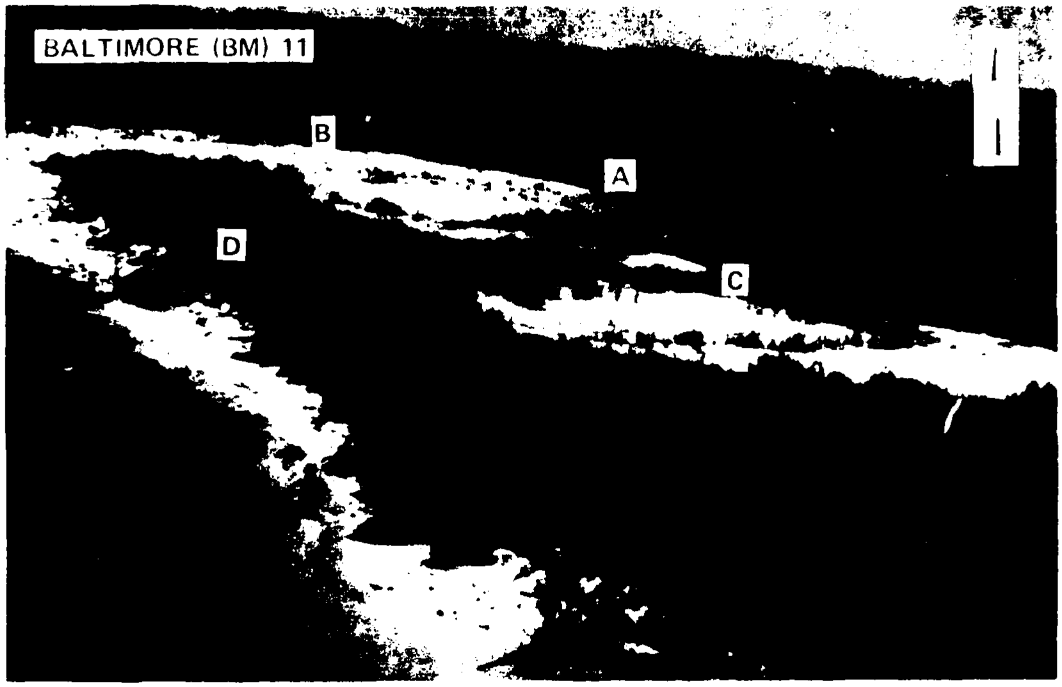


Photo [illegible]. Site [illegible]

BALTIMORE (BM) 12

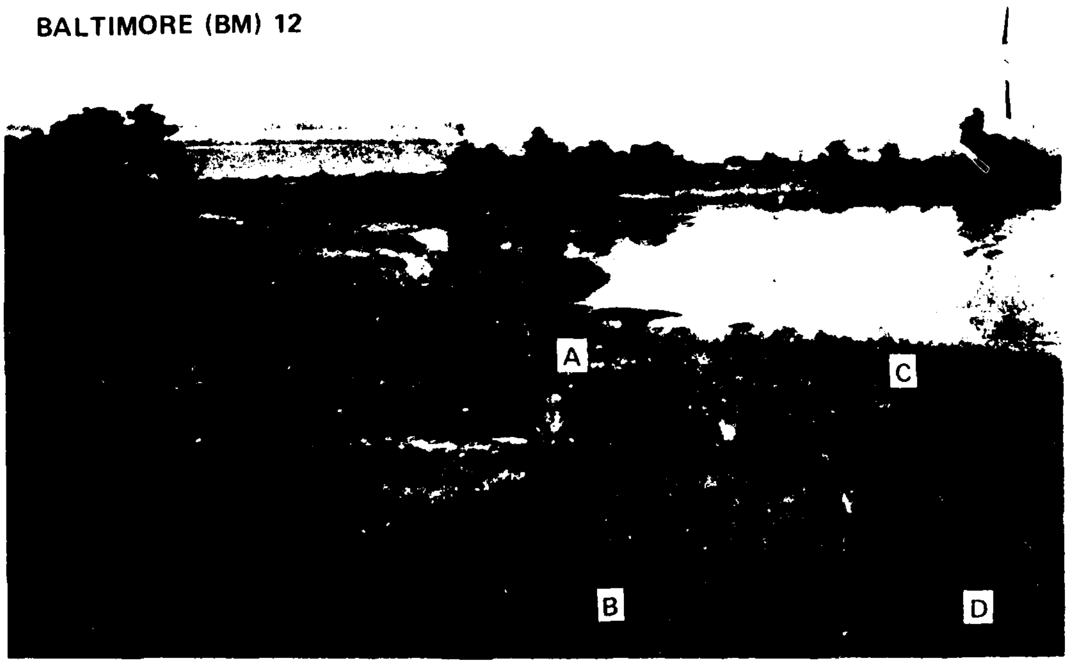


Photo 61. Site [illegible]

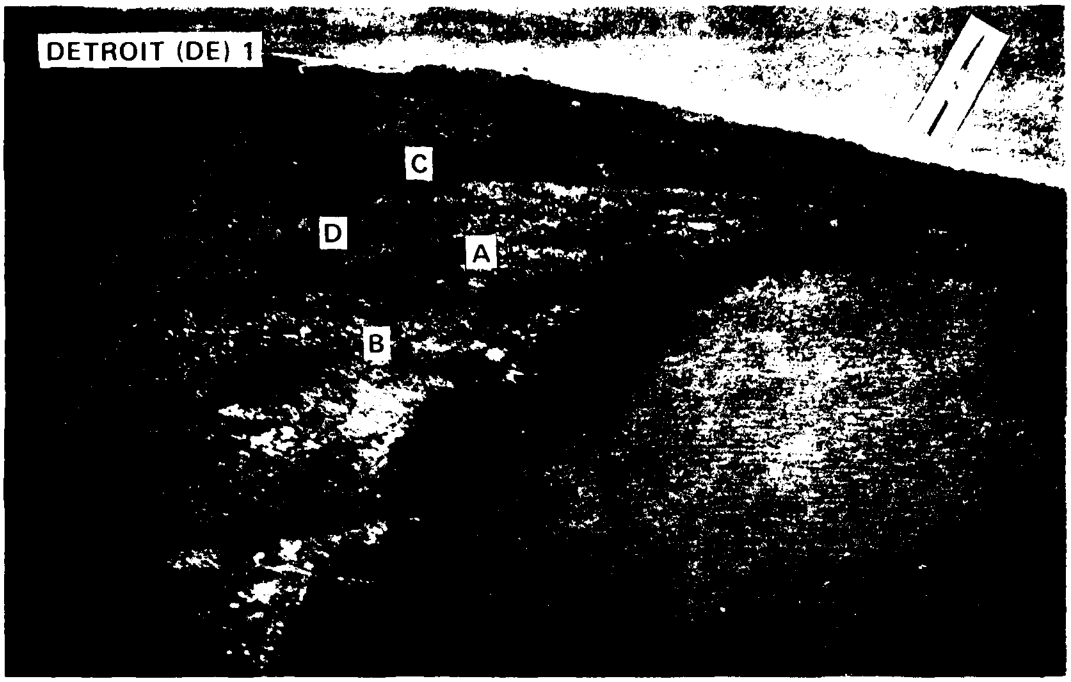


Photo 62. Site DE1

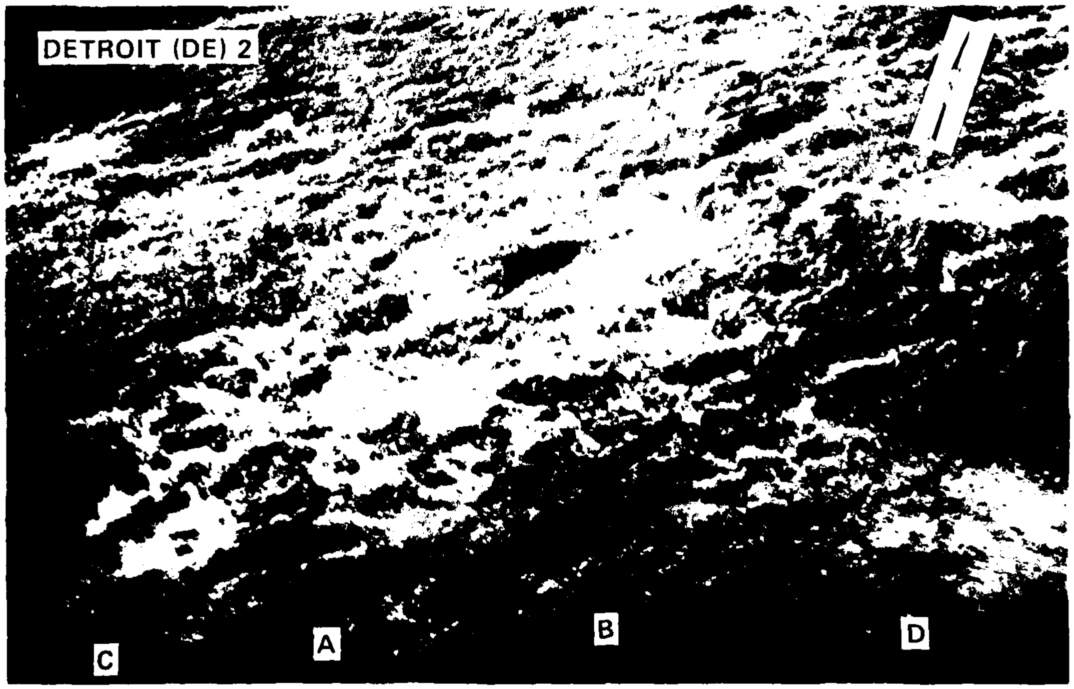


Photo 63. Site DE2

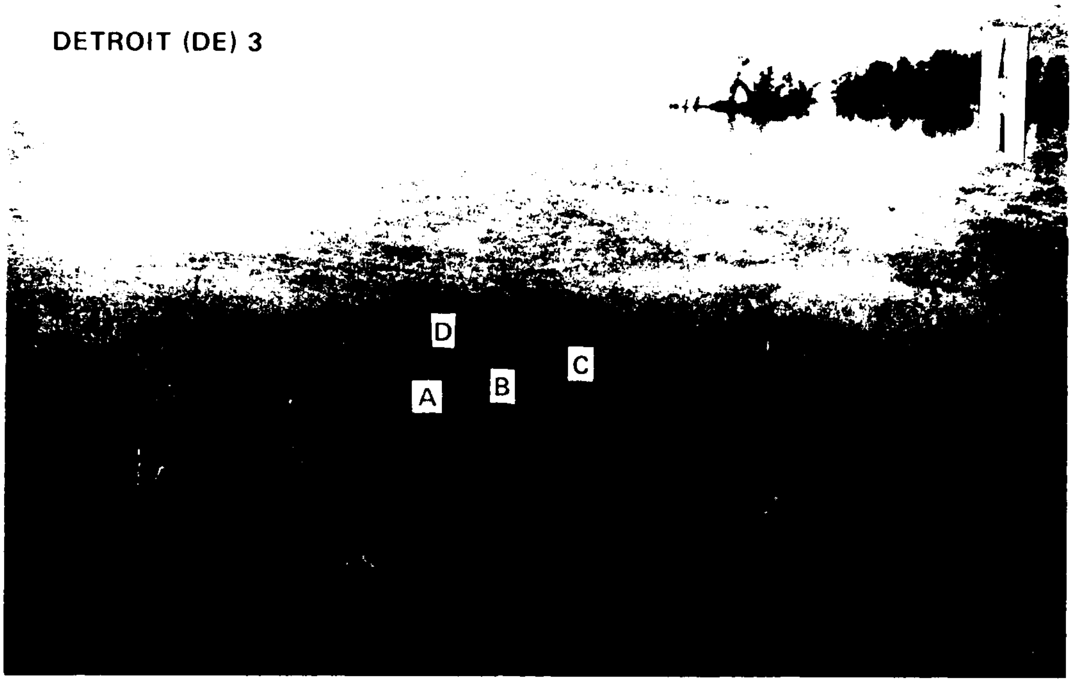


Photo 64. Site DE3

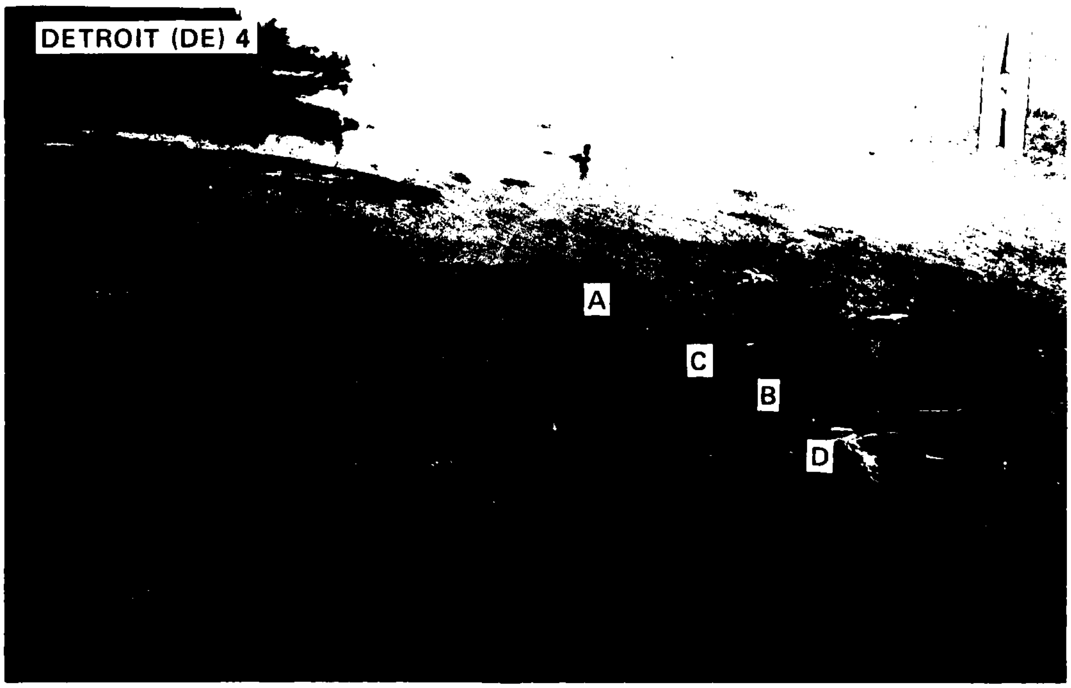


Photo 65. Site DE4

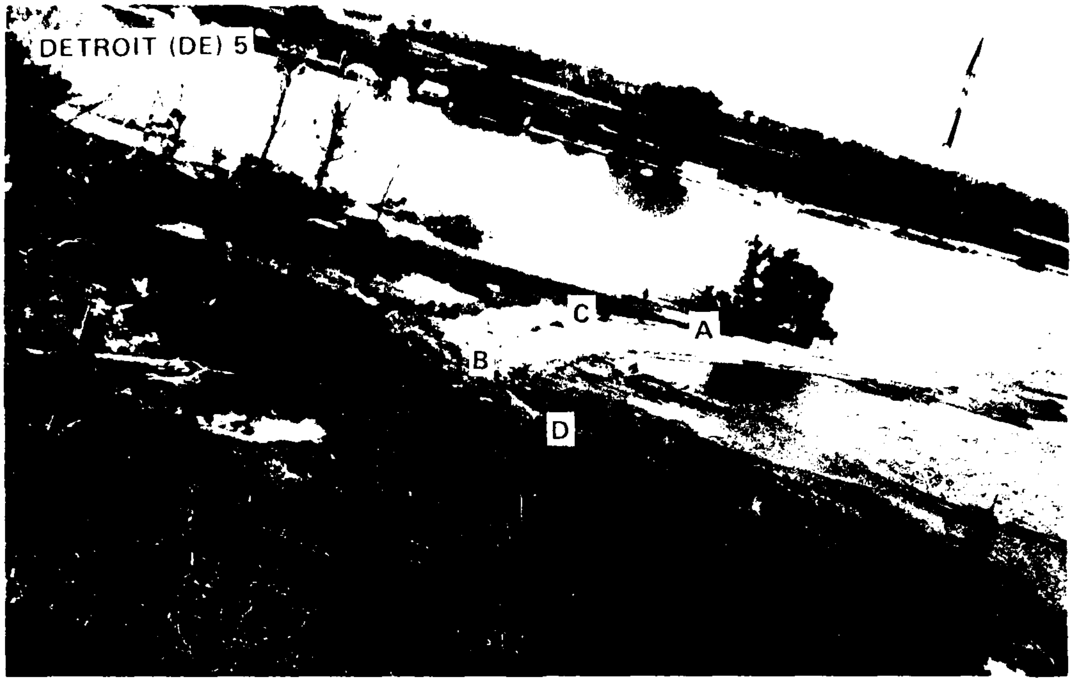


Photo 66. Site DE5

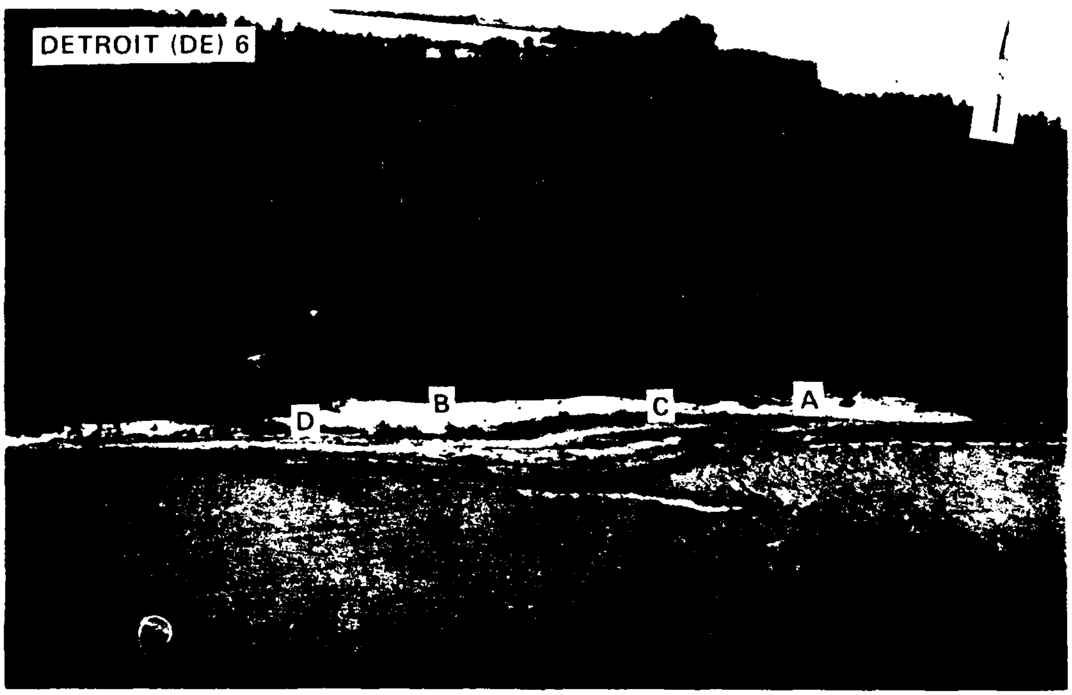


Photo 67. Site DE6

Photo 68. Site DE7

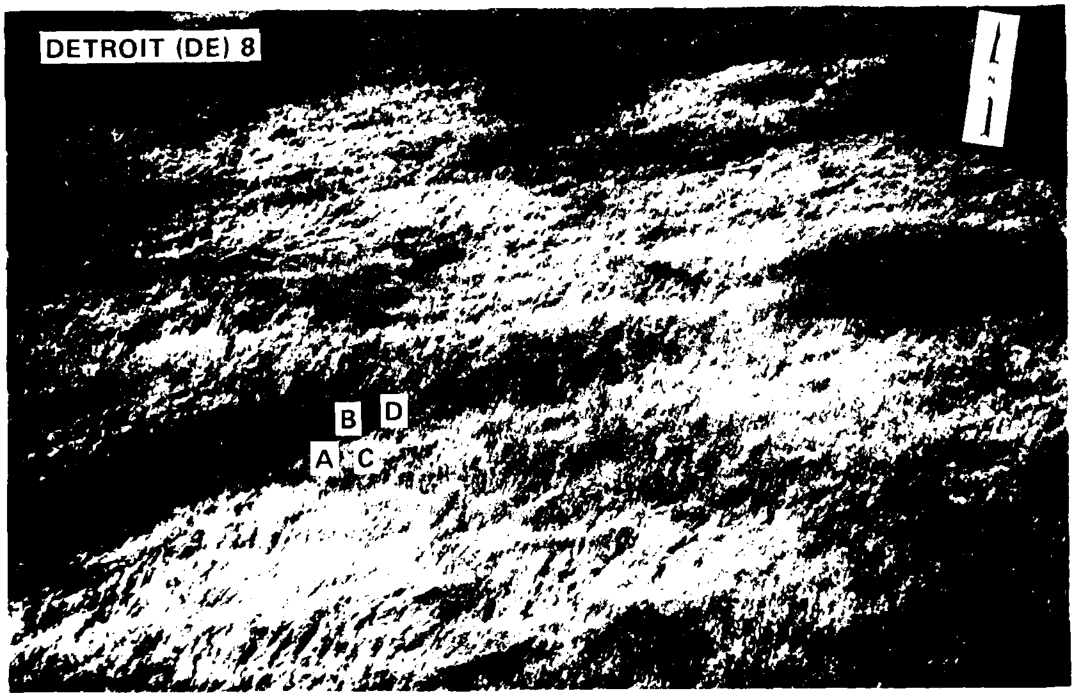


Photo 69. Site DE8

MENOMINEE (ME) 1

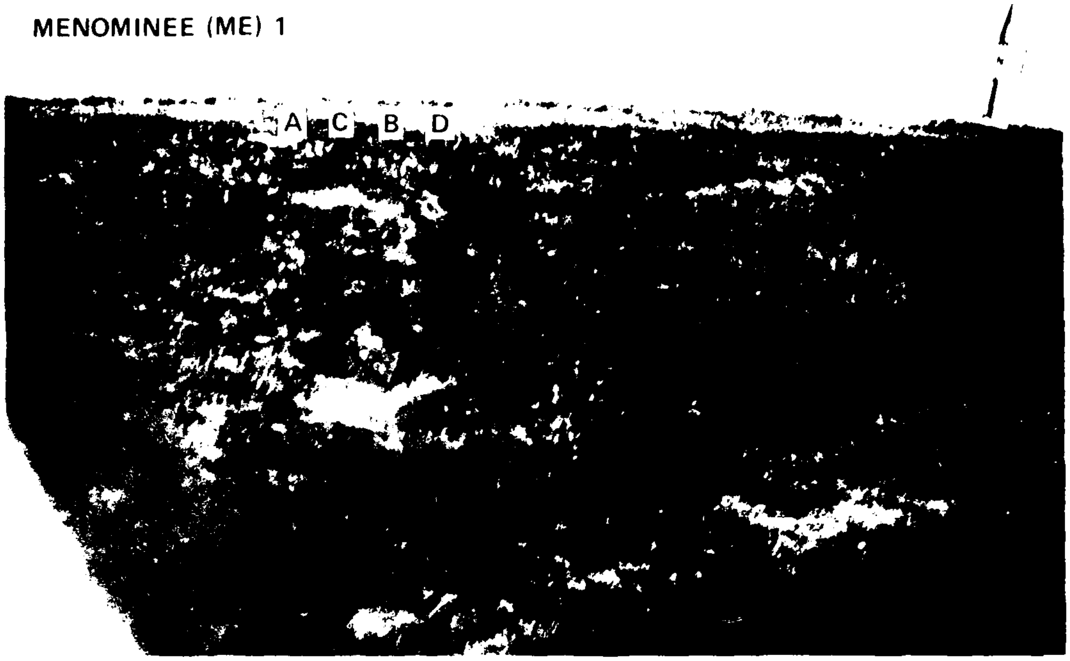


Photo 70. Site ME1

Photo 71. Site ME2

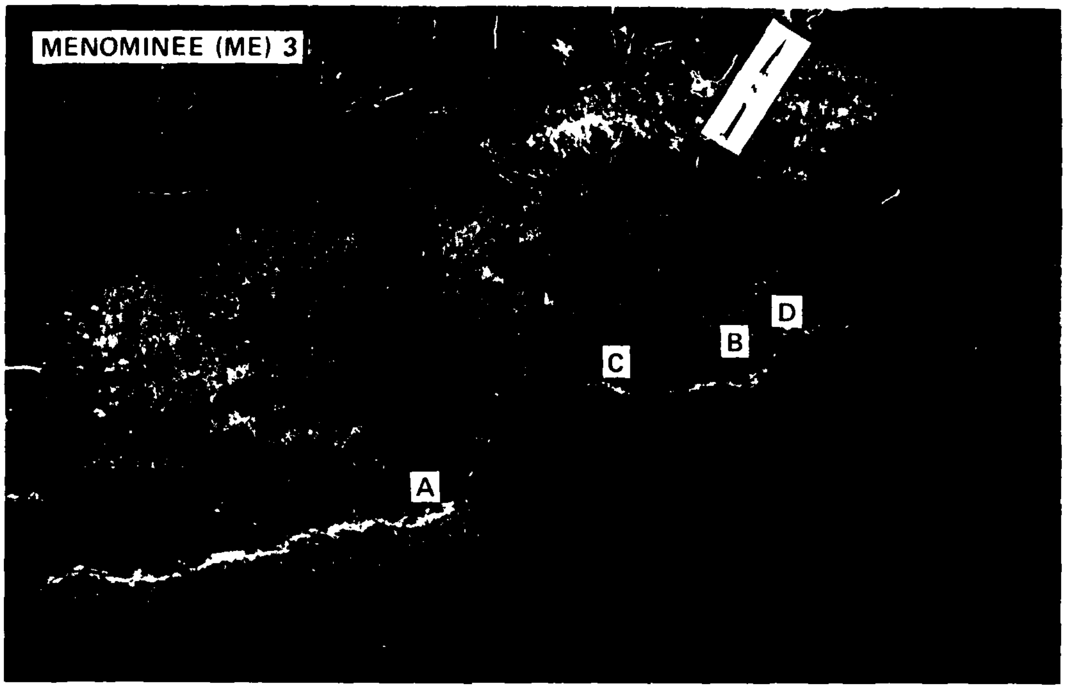


Photo 72. Site ME3

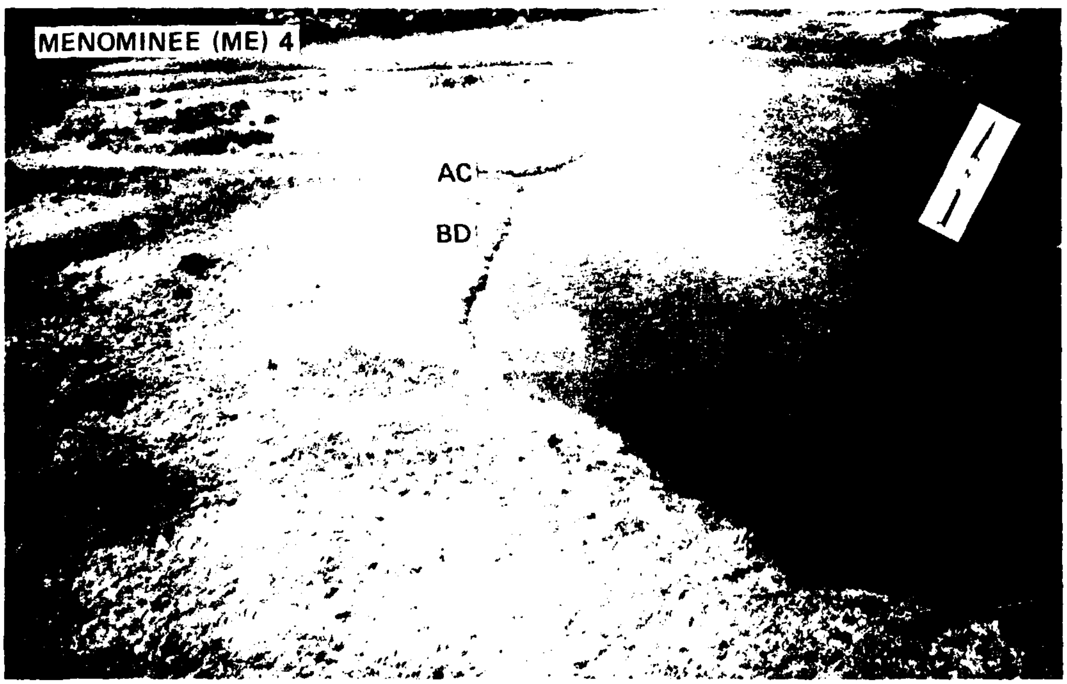


Photo 73. Site ME4

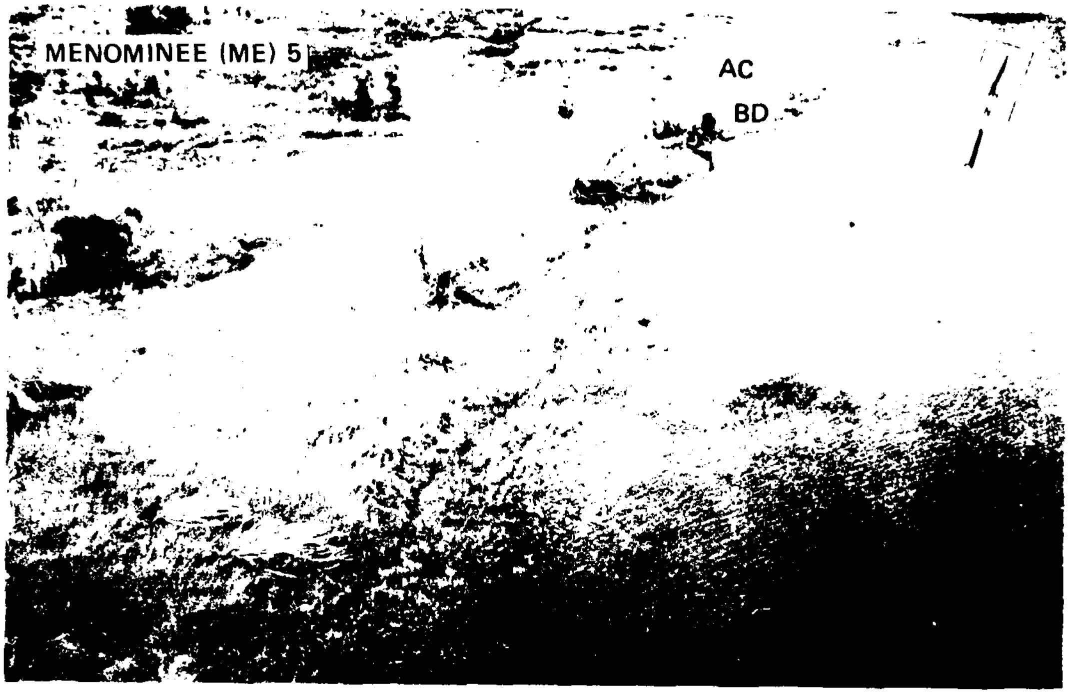


Photo 74. Site ME5

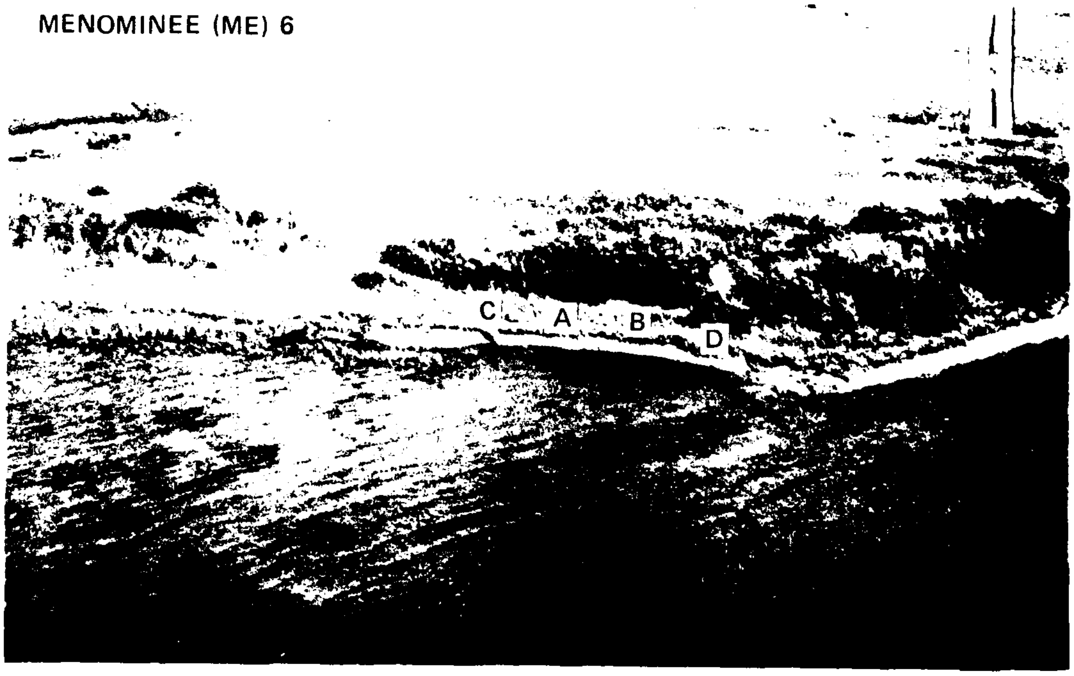


Photo 75. Site ME6

MILWAUKEE (MW) 1

Photo 76. Site MW1

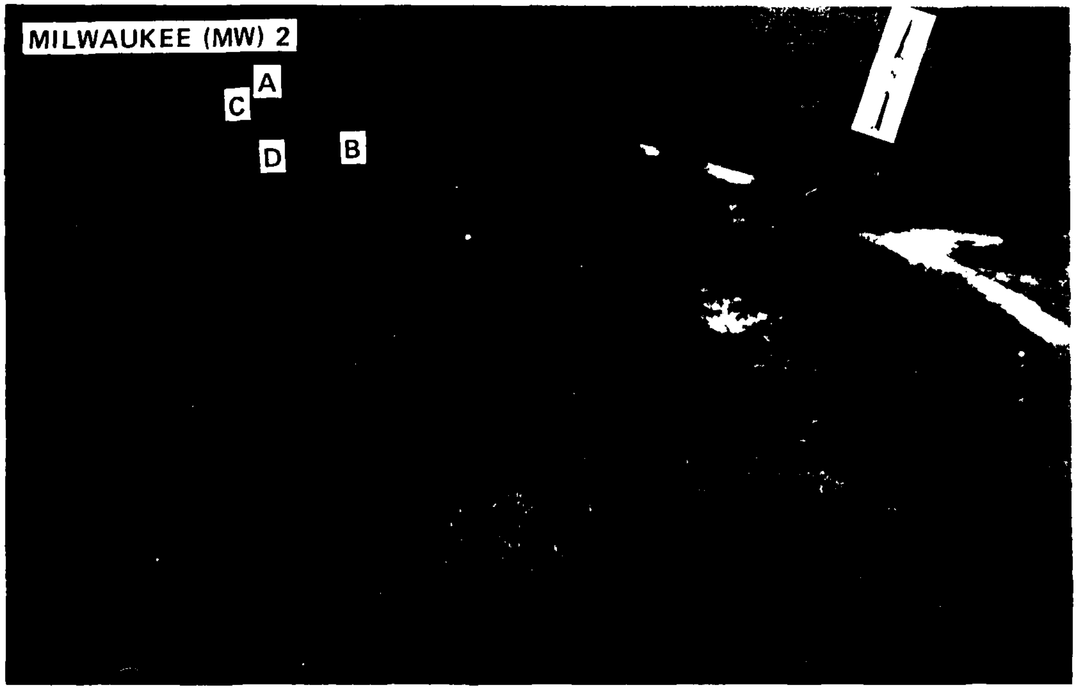
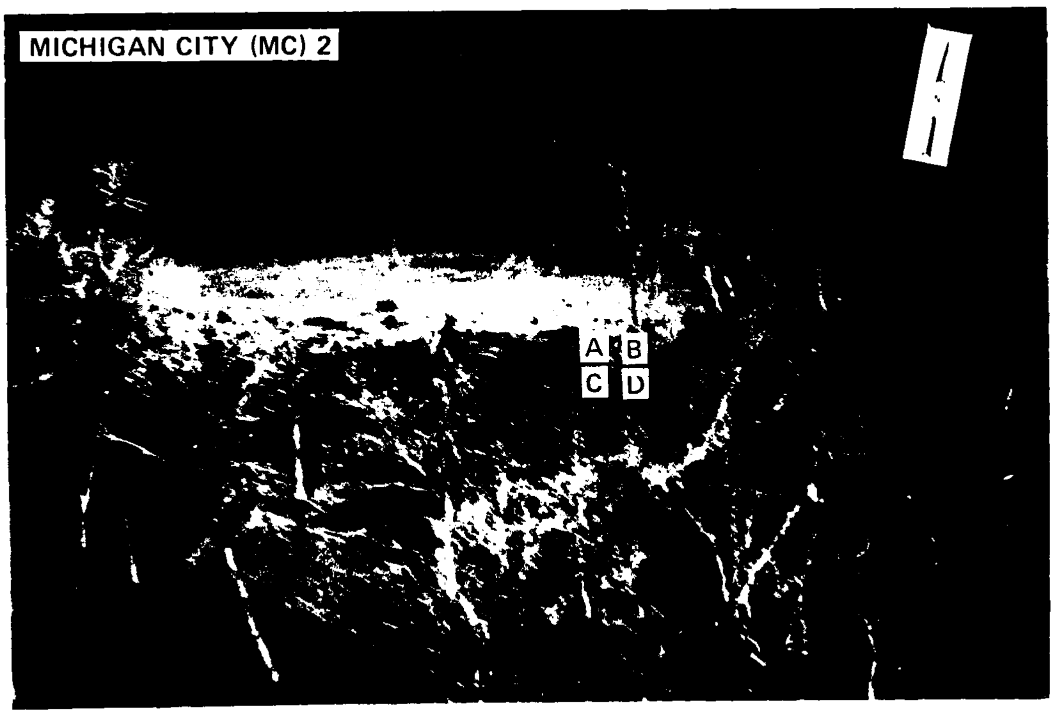


Photo 77. Site MW2

Photo 78. Site MC1



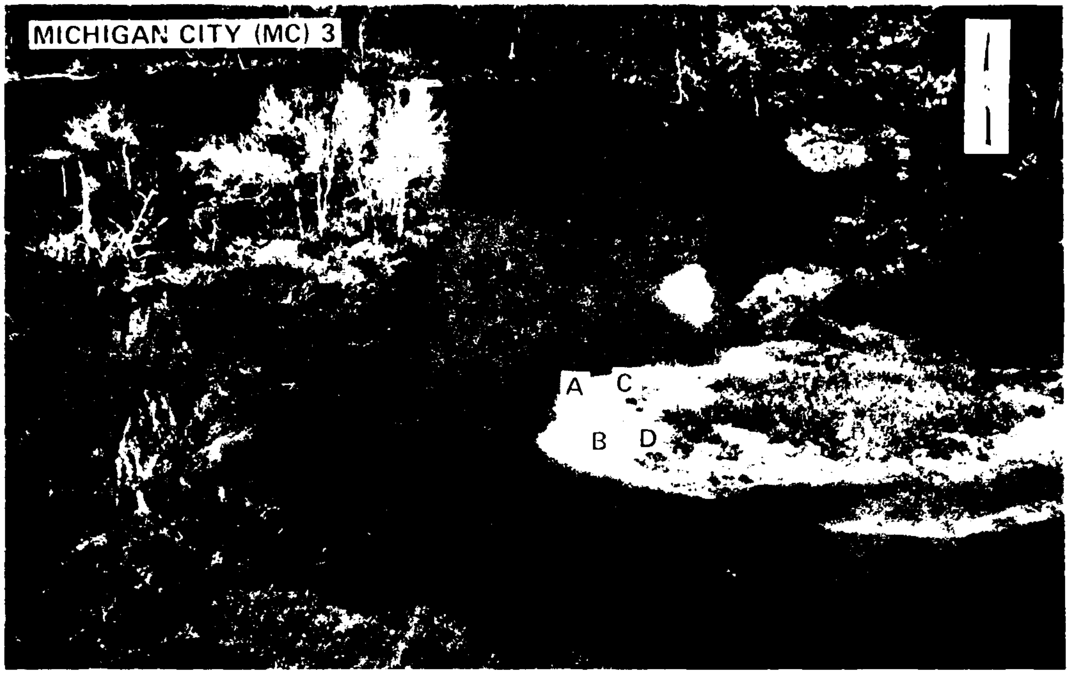


Photo 80. Site MC3

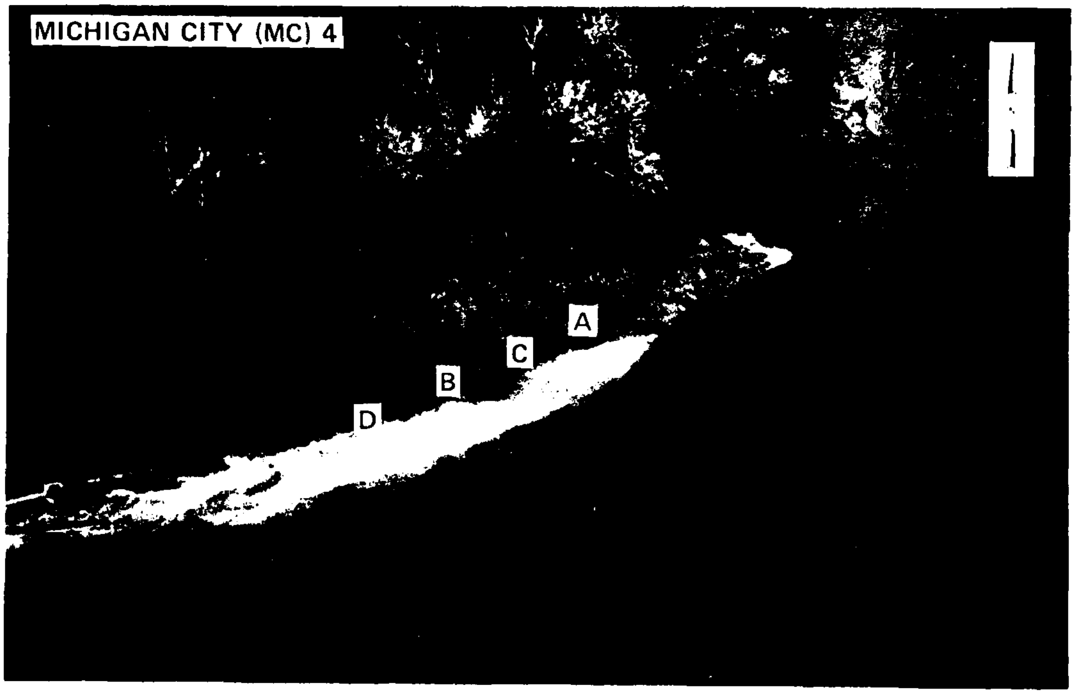


Photo 81. Site MC4

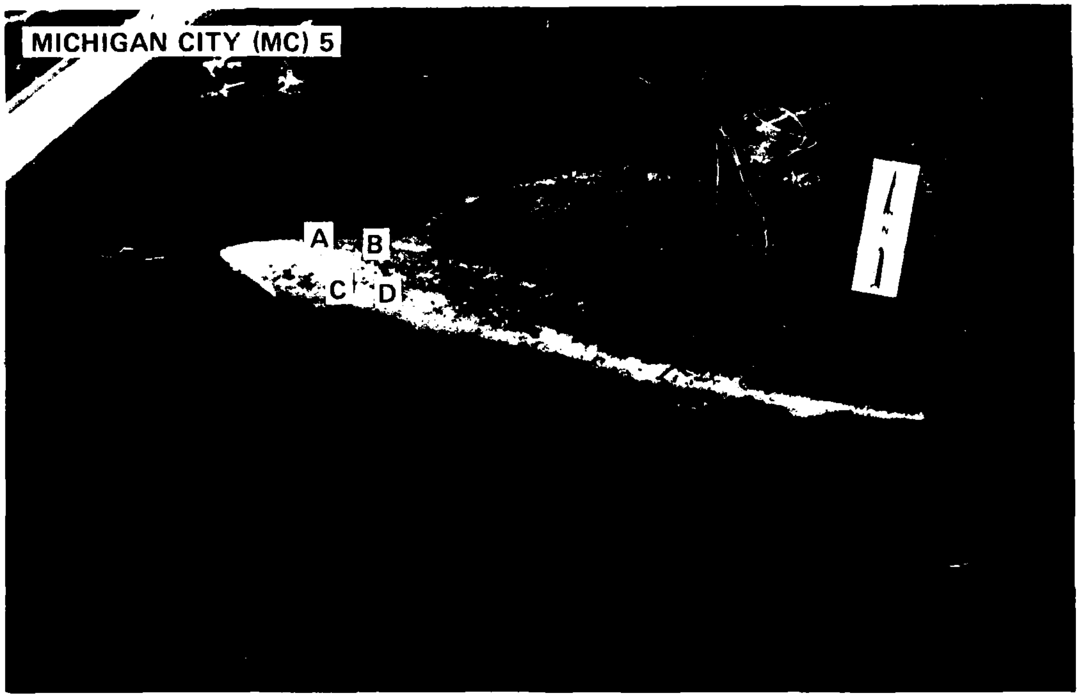


Photo 82. Site MC5

PHOTO NOT AVAILABLE ON
MICHIGAN CITY SITE 6

Photo 83. Site MC6

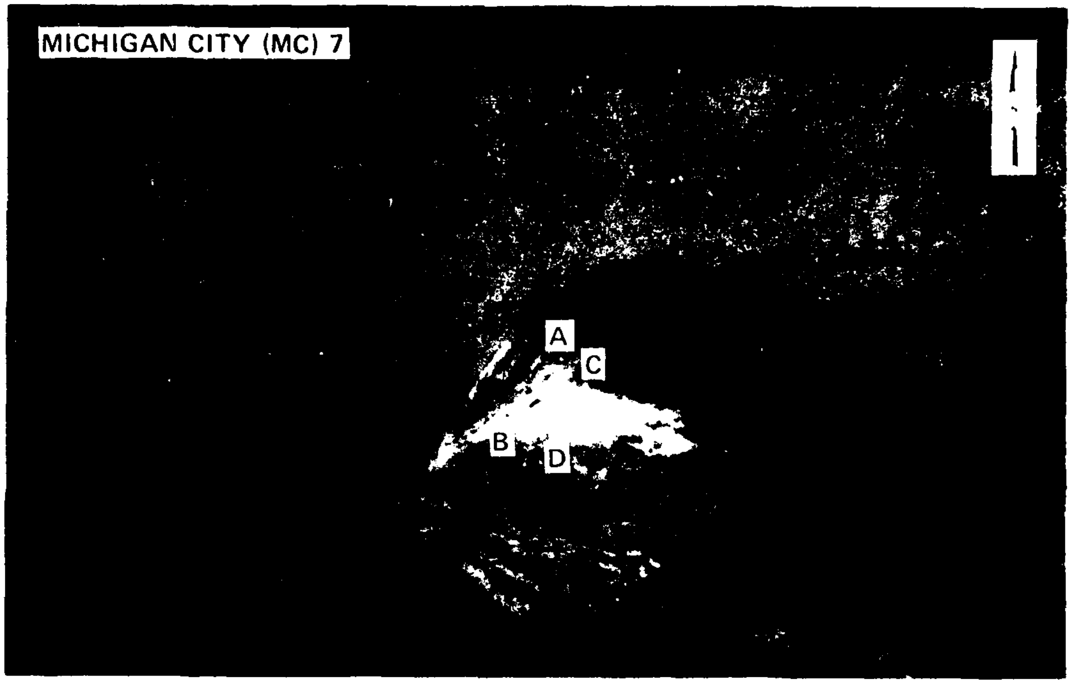


Photo 84. Site MC7

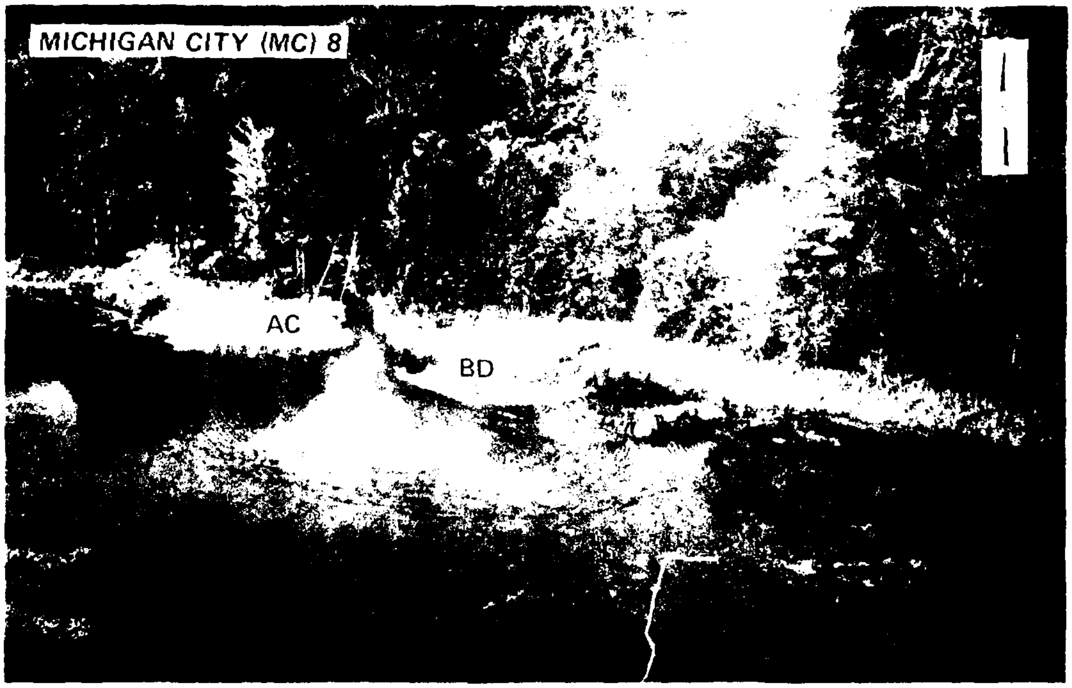


Photo 85. Site MC8

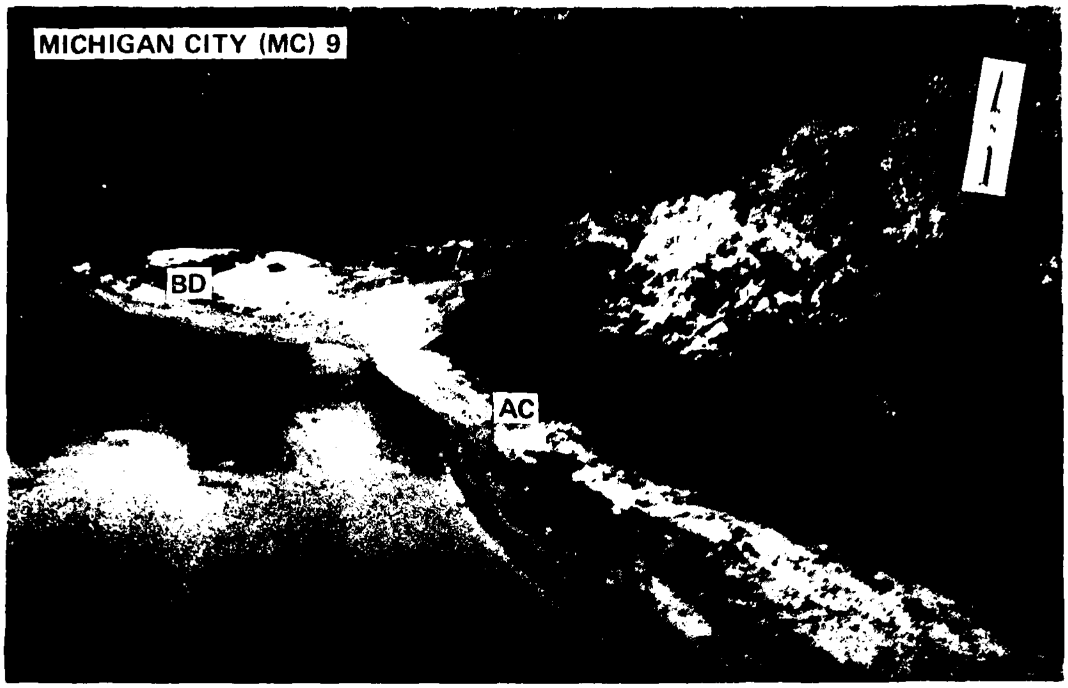


Photo 86. Site MC9

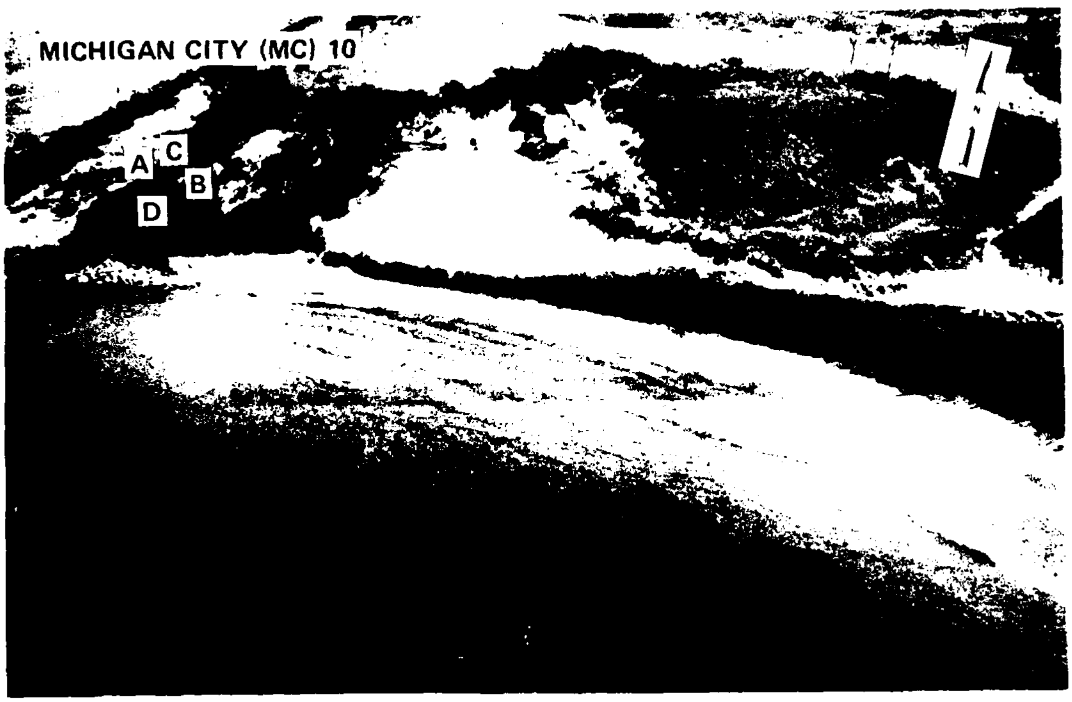


Photo 87. Site MC10

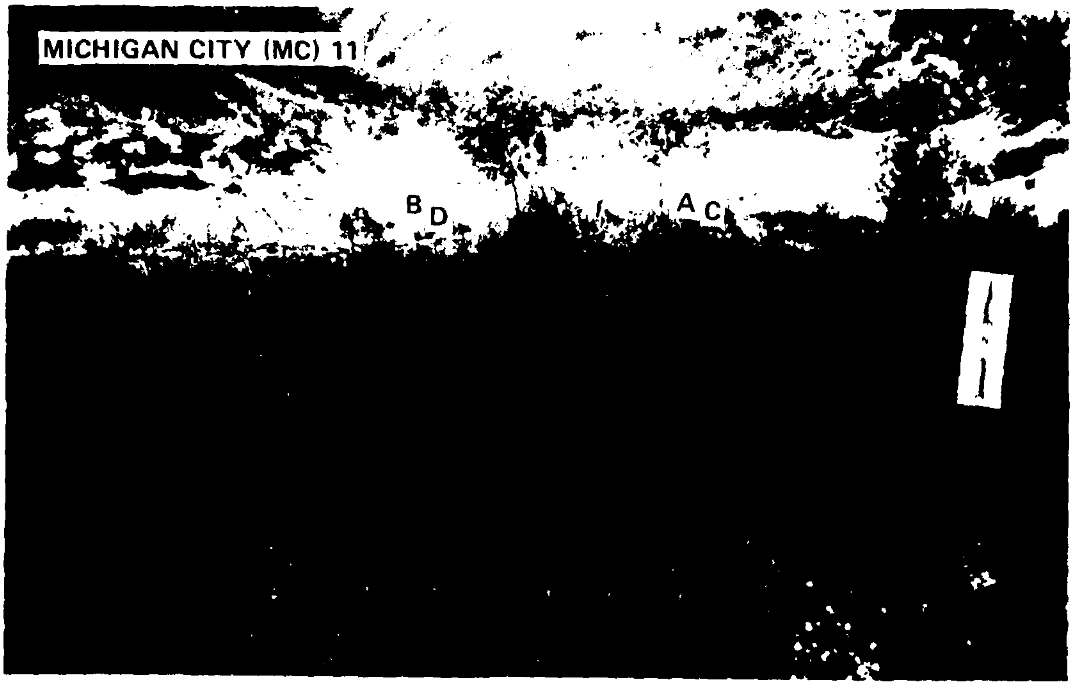


Photo 88. Site MC11

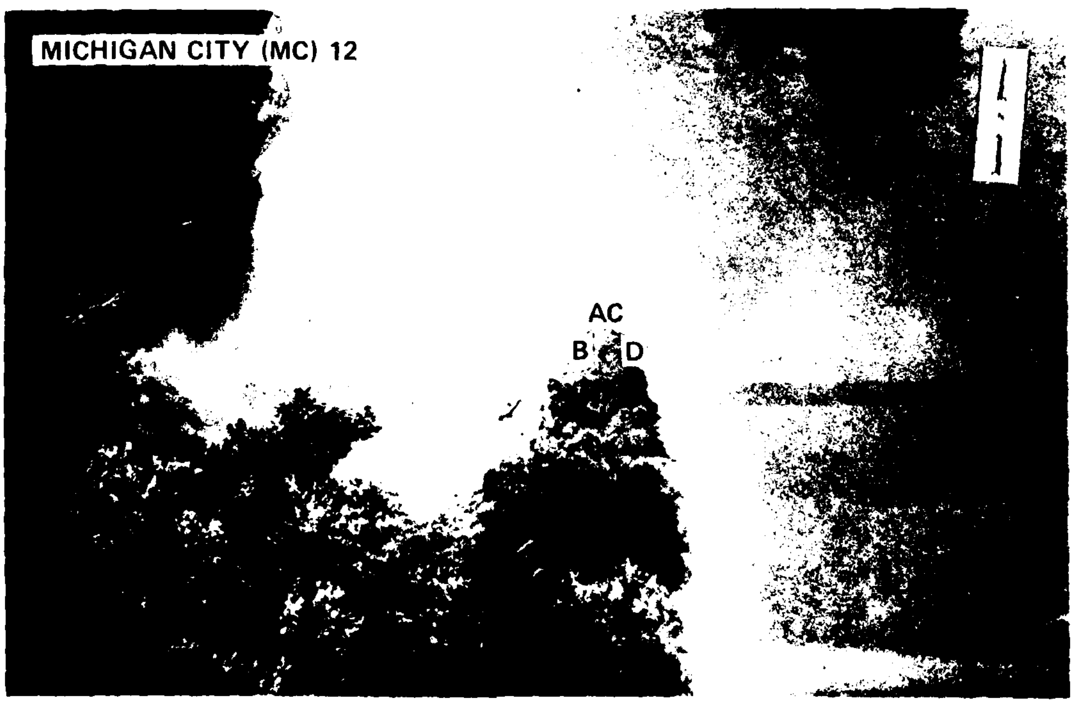


Photo 89. Site MC12

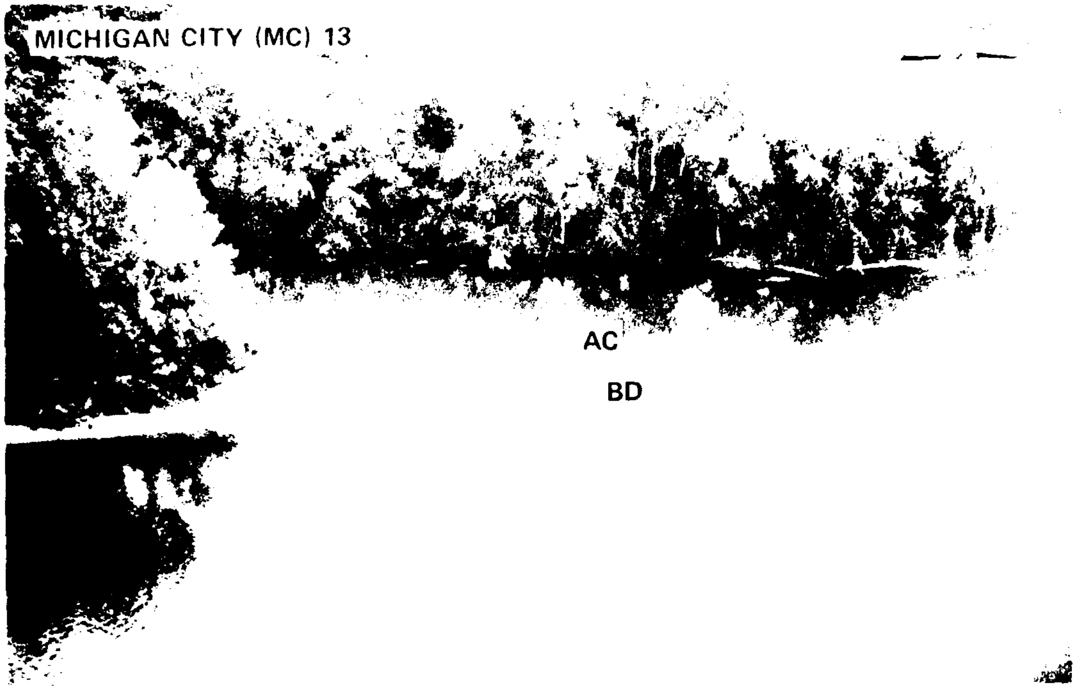


Photo 90. Site MC13

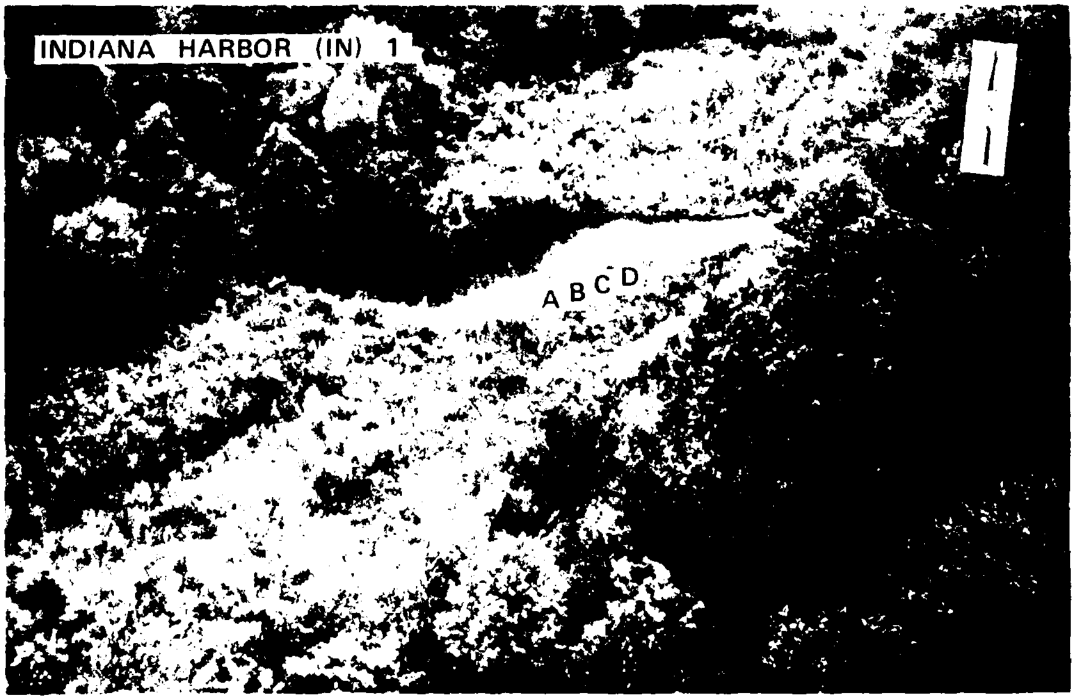


Photo 91. Site IN1

APPENDIX B: SALTWATER COLLECTION SITE PHYSICAL DATA

Saltwater Collection Site Physical Data

General Area	Collection Site No.	Collection Date	USGS Topographic Sheet 7.5'	North Latitude	West Longitude	Prevailing Wind Direction	Tidal Range, ft	Tidal Range, m
Corpus Christi, Tex.	CC1	18 Jul 78	Corpus Christi, Tex.	27°41'	97°30'	S	2.2	0.67
	CC2		Corpus Christi, Tex.	27°41'	97°31'			
	CC3		Taft, Tex.	27°52.5'	97°30.5'			
	CC4		Corpus Christi, Tex.	27°52'	97°29'			
	CC5		Corpus Christi, Tex.	27°52'	97°27'			
	CC6		Portland, Tex.	27°52'	97°20'			
	CC7		St. Charles Bay, Tex.	28°10'	96°57'			
	CC8		Portland, Tex.	28°10'	96°53'			
	CC9		Mesquite Bay, Tex.	28°10'	96°49.5'			
	CC10	19 Jul 78	Port Lavala, East, Tex.	28°30.5'	96°30.5'			
	CC11		Palacio, NE, Tex.	28°37'	96°06.5'			
	CC12		Cedar Lakes, West, Tex.	28°50.8'	95°32'			
	CC13		Christmas Point, Tex.	29°01.5'	94°14.5'			
	CC14		Virginia Point, Tex.	29°18'	94°56'			
	CC15		Frozen Point, Tex.	29°34.5'	94°34'			
New Orleans, La.	NO1	20 Jul 78	Bay St. Louis, Miss.	30°21.5'	89°18'	--	2.0	0.61
	NO2		Grand Island Pass, Miss.-La.	30°36'	89°27.5'	--		
	NO3		Alligator Point, La.	30°31.2'	89°43'	--		
	NO4		Lake Eloi, La.	29°45.5'	89°23.7'	--		
	NO5		Main Pass, La.	29°26'	89°06'	--		
	NO6		Burns, La.	29°21'	89°33'	--		
	NO7		Bay Batiste, La.	29°27'	89°35'	--		
	NO8		Caminado Pass, La.	29°13'	90°06'	--		
	NO9		Bay Desgris, La.	29°25.5'	90°04'	--	2.2	0.67
	NO10	21 Jul 78	Grand Bayou Du Large, La.	29°10.5'	90°57'	--		
	NO11	21 Jul 78	Point Au Fer, La.	29°28'	91°20'	--		
	NO12	21 Jul 78	Bayou Lucien, La.	29°30.1'	91°53.2'	--		
Jacksonville, Fla.	JV1	01 Aug 78	Amelia City, Fla.	30°31.0'	81°25.6'	SW	6.0	1.83
	JV2		Fernandina Beach, Fla.	30°43.0'	81°28.5'		6.0	1.83
	JV3		Jekyll Island, Ga.	31°01.0'	81°26.0'		9.0	2.74
	JV4		Isle of Hope, Ga.	31°52.5'	81°01.5'			
	JV5		Rockville, S. C.	32°01.5'	80°50.5'	N		
	JV6		James Island, S. C.	32°38.5'	79°58.0'			
	JV7		Awendaw, S. C.	33°01.7'	79°32.0'		4.5	1.37
	JV8		McClellanville, S. C.	33°01.0'	79°24.0'		4.5	1.37
	JV9	02 Aug 78	Santee Point, S. C.	35°11.0'	79°11.5'		5.0	1.52
	JV10		Shallotte, N. C.	33°56.0'	78°22.5'	SW		
	JV11		Kure Beach, N. C.	33°56.2'	77°56.0'	SW		
	JV12		Carolina Beach, N. C.	34°04.0'	77°53.5'	SW		

(Continued)

General Area	Collection Site No.	Collection Date	USGS Topographic Sheet 7.5'	North Latitude	West Longitude	Prevailing Wind Direction	Tidal Range, ft	Tidal Range, m
New York, N. Y.	NY1	08 Aug 78	Bridgeport, Conn.	41°08.5'	73°12.7'	SW	7.2	2.19
	NY2			41°09.3'	73°12.8'			
	NY3			41°10.0'	73°09.0'			
	NY4			41°09.0'	73°08.0'			
	NY5			41°09.2'	73°07.8'			
	NY6		Milford, Conn.	41°09.1'	73°06.0'		3.0	0.91
	NY7		Mystic, Conn.	41°20.0'	71°52.5'		3.2	0.97
	NY8	09 Aug 78	Lloyd Harbor, N. Y.-Conn.	40°57.7'	73°24.0'	--	4.7	1.43
	NY9		Sandy Hook, N. J.	40°25.5'	74°00.5'	S		
	NY10		Ship Bottom, N. J.	39°44.0'	74°05.0'			
	NY11		Brigantine Inlet	39°28.5'	74°19.0'			
	NY12		Sea Isle City, N. J.	39°12.0'	74°39.0'			
Baltimore, Md.	BM1	10 Aug 78	Gibson Island, Md.	39°01.0'	76°24.5'	NE	1.3	0.40
	BM2		Sparrows Point, Md.	39°14.0'	76°24.0'			
	BM3		Sparrows Point, Md.	39°13.0'	76°25.0'			
	BM4		Middle River, Md.	39°17.0'	76°23.0'			
	BM5		Middle River, Md.	39°19.0'	76°24.0'			
	BM6		Middle River, Md.	39°16.0'	76°26.0'			
	BM7	11 Aug 78	Deak, Md.	38°49.0'	76°30.1'			
	BM8		Reedville, Va.	37°47.0'	76°17.0'	SW	3.1	0.93
	BM9		New Point Comfort, Va.	37°20.0'	76°16.0'	SW		0.93
	BM10		Townsend, Va.	37°08.0'	75°56.2'	SW		0.93
	BM11		Kedgas Straits, Md.	38°01.0'	76°03.0'	--		0.95
	BM12		Longgood Creek, Md.	39°01.0'	76°12.5'	NE	1.3	0.40

APPENDIX C: FRESHWATER COLLECTION SITE PHYSICAL DATA

Freshwater Collection Site Physical Data

General Area	Collection Site No.	Collection Date	USGS Topographic Sheet	North Latitude	West Longitude	Prevailing Wind Direction
Detroit, Mich.	DE1	16 Aug 78	Rockwood, Mich. 7.5'	42°01.0'	83°12.0'	SW
	DE2	16 Aug 78	Mt Clemens East, Mich. 7.5'	42°32.0'	82°38.0'	
	DE3	17 Aug 78	Wyandotte, Mich. 7.5'	42°08.0'	83°07.5'	
	DE4		Rockwood, Mich. 7.5'	42°04.5'	83°10.0'	
	DE5		Estral Beach, Mich.-Ohio 7.5'	42°57.5'	83°15.0'	
	DE6		Stony Point, Mich. 7.5'	41°52.5'	83°21.0'	
	DE7		Erie, Mich.-Ohio 7.5'	41°45.5'	83°26.0'	
	DE8		Mt Clemens East, Mich. 7.5'	42°32.2'	82°38.0'	
	DE9		Mt Clemens East, Mich. 7.5'	42°32.2'	82°38.0'	
Menominee, Mich.	ME1	22 Aug 78	Little Sturgeon, Wis. 15'	44°58.5'	87°37.5'	
	ME2		Little Sturgeon, Wis. 15'	44°58.2'	87°40.0'	
	ME3		Oconto, Wis. 15'	40°57.0'	87°48.0'	
	ME4		Oconto, Wis. 15'	44°55.2'	87°50.5'	
	ME5		Oconto, Wis. 15'	44°50.0'	87°52.0'	
	ME6		Marinette, Wis.-Mich. 7.5'	45°04.5'	87°35.0'	
Milwaukee, Wis.	MW1	23 Aug 78	Zion, Ill. 7.5'	42°25.0'	87°45.0'	W
	MW2	23 Aug 78	Zion, Ill. 7.5'	42°25.0'	87°45.0'	W
Michigan City, Ind.	MC1	24 Aug 78	Fennville, Mich. 15'	42°38.0'	86°09.0'	SSW
	MC2				86°08.5'	
	MC3				86°06.0'	
	MC4				86°05.0'	
	MC5			42°37.7'	86°04.5'	
	MC6			42°37.5'	86°04.0'	
	MC7	25 Aug 78	Grand Haven, Mich. 7.5'	43°02.5'	86°09.3'	
	MC8		Port Sheldon, Mich. 7.5'	42°54.0'	86°11.5'	
	MC9		Benton Harbor, Mich. 7.5'	42°01.0'	86°23.0'	
	MC10		Michigan City West, Mich. 7.5'	41°42.6'	86°55.2'	--
	MC11		Three Oaks, Mich. 7.5'	41°41.5'	86°34.5'	SSW
	MC12		Sodus, Mich. 7.5'	42°58.5'	86°21.0'	SSW
	MC13		Sodus, Mich. 7.5'	42°00.0'	86°21.0'	SSW
Indiana Harbor, Ind.	IN1		Portage, Ind. 7.5'	41°35.2'	87°07.6'	--

APPENDIX D: *CYPERUS* SPECIES COLLECTED BY SITE

Cyperus Species Collected by Site

Collection Site	Location	Sample	Species	WES Herbarium Number
DE1	Wayne County, Mich.	A	*C. odoratus*	0001FS76
			C. erythrorhyzos	
		B	*C. odoratus*	
		C		
		D		
		E		
			C. strigosus	
DE2	Macomb County, Mich.	A	*C. odoratus*	0002FS78
		B	*C. Englemanni**	
		C	*C. odoratus*	
			*C. Englemanni**	
		D	*C. Englemanni**	
		E	*C. Englemanni**	
DE3	Wayne County, Mich.	A	*C. strigosus*	0003FS78
		B		
		C		
		D		
		E		
DE4	Wayne County, Mich.	A	*C. odoratus*	0004FS78
			C. strigosus	
		B	*C. odoratus*	
			C. Englemanni	
		C	*C. odoratus*	
			C. esculentus	
		D	*C. odoratus*	
			C. strigosus	

(Continued)

* New county record for this species.

Collection Site	Location	Sample	Species	WES Herbarium Number
DE4 (Continued)		E	*C. odoratus*	
			C. strigosus	
DE5	Monroe County, Mich.	A	*C. odoratus*	0005FS78
		B		
		C		
		D		
		E		
DE6	Monroe County, Mich.	A	*C. odoratus*	0006FS78
		B	*C. strigosus*	
		C	*C. strigosus*	
		D	*C. odoratus*	
			C. strigosus	
		E	*C. odoratus*	
			C. strigosus	
DE7	Monroe County, Mich.	A	*C. odoratus*	0007FS78
		B	*C. odoratus*	
			C. strigosus	
		C	*C. odoratus*	
		D	*C. odoratus*	
		E	*C. odoratus*	
DE8	Macomb County, Mich.	A	*C. Englemanni**	0008FS78
		B	*C. Englemanni**	
		C	*C. Englemanni**	
			C. erythrorhyzos	
		D	*C. Englemanni**	
		E	*C. Englemanni**	
DE9	Macomb County, Mich.	A	*C. Englemanni**	0009FS78
			C. erythrorhyzos	

(Continued)

* New county record for this species.

Collection Site	Location	Sample	Species	WES Herbarium Number
DE9 (Continued)		B	*C. Englemanni**	
		C		
		D		
		E		
			C. erythrorhyzos	
ME1	Marinette County, Wis.	A	*C. Englemanni**	0010FS78
		B		
		C		
		D		
		E		
			C. strigosus	
ME2	Marinette County, Wis.	A	*C. Englemanni**	0011FS78
		B		
		C		
		D		
		E		
			C. strigosus	
ME3	Oconto County, Wis.	A	*C. Englemanni**	0012FS78
		B	*C. strigosus*	
		C	*C. Englemanni**	
		D	*C. Englemanni**	
		E	*C. strigosus*	
ME4	Oconto County, Wis.	A	*C. Englemanni**	0013FS78
		B		
		C		
		D		
		E		

(Continued)

* New county record for this species.

Collection Site	Location	Sample	Species	WES Herbarium Number
ME5	Onconto County, Wis.	A	*C. Englemanni**	0014FS78
		B		
		C		
		D		
		E		
ME6	Marinette County, Wis.	A	*C. Englemanni*	0015FS78
		B		
		C		
		D		
		E		
MW1	Lake County, Ill.	A	*C. strigosus*	0016FS78
		B		
		C		
		D		
		E		
			C. odoratus	
MW2	Lake County, Ill.	A	*C. strigotus*	0017FS78
		B		
		C		
		D		
		E		
MC1	Allegan County, Mich.	A	*C. erythrorhyzos*	0018FS78
		B		
		C		
		D		
		E	*C. Englemanni* *C. odoratus*	

(Continued)

* New county record for this species.

(Sheet 4 of 8)

Collection Site	Location	Sample	Species	WES Herbarium Number
MC2	Allegan County, Mich.	A	*C. erythrorhyzos*	0019FS78
		B	*C. erythrorhyzos*	
			C. Englemanni	
		C	*C. erythrorhyzos*	
			C. Englemanni	
		D	*C. erythrorhyzos*	
		E	*C. erythrorhyzos*	
			C. Englemanni	
MC3	Allegan County, Mich.	A	*C. erythrorhyzos*	0020FS78
			C. odoratus	
		B	*C. erythrorhyzos*	
			C. odoratus	
			C. strigosus	
		C	*C. erythrorhyzos*	
			C. odoratus	
		D	*C. erythrorhyzos*	
			C. odoratus	
			C. strigosus	
		E	*C. erythrorhyzos*	
			C. odoratus	
			C. strigosus	
MC4	Allegan County, Mich.	A	*C. erythrorhyzos*	0021FS78
			*C. odoratus**	
		B	*C. erythrorhyzos*	
			*C. odoratus**	
		C	*C. erythrorhyzos*	
			*C. odoratus**	
		D	*C. erythrorhyzos*	
			*C. odoratus**	

(Continued)

* New county record for this species.

Collection Site	Location	Sample	Species	WES Herbarium Number
MC4 (Continued)		E	*C. erythrorhyzos*	
			*C. odoratus**	
MC5	Allegan County, Mich.	A	*C. erythrorhyzos*	0022FS78
			*C. odoratus**	
		B	*C. erythrorhyzos*	
			*C. odoratus**	
		C	*C. erythrorhyzos*	
			*C. odoratus**	
			C. strigosus	
		D	*C. odoratus**	
			C. strigosus	
		E	*C. erythrorhyzos*	
			*C. odoratus**	
			C. strigosus	
MC6	Allegan County, Mich.	A	*C. odoratus*	0023FS78
		B	*C. Englemanni**	
		C	*C. odoratus**	
		D	*C. erythrorhyzos*	
		E	*C. erythrorhyzos*	
			*C. odoratus**	
MC7	Ottawa County, Mich.	A	*C. odoratus*	0024FS78
			C. strigosus	
		B	*C. odoratus*	
			C. erythrorhyzos	
			C. Englemanni	
		C	*C. odoratus*	
			C. Englemanni	
		D	*C. odoratus*	
			C. Englemanni	

(Continued)

* New county record for this species.

Collection Site	Location	Sample	Species	WES Herbarium Number
MC7 (Continued)		E	*C. odoratus*	
			C. Englemanni	
			C. strigosus	
MC8	Ottawa County, Mich.	A	*C. Englemanni*	0025FS78
		B	*C. strigosus*	
		C	*C. Englemanni*	
		D	*C. Englemanni*	
		E	*C. Englemanni*	
MC9	Berrien County, Mich.	A	*C. odoratus*	0026FS78
			C. strigosus	
		B	*C. odoratus*	
		C	*C. odoratus*	
		D	*C. odoratus*	
			C. strigosus	
		E	*C. odoratus*	
			C. strigosus	
MC10	La Porte County, Ind.	A	*C. odoratus*	0027FS78
		B		
		C		
		D		
		E		
MC11	Berrien County, Mich.	A	*C. strigosus*	0028FS78
		B	*C. strigosus*	
			C. erythrorhyzos	
		C	*C. strigosus*	
		D	*C. odoratus*	
		E	*C. strigosus*	
MC12	Berrien County, Mich.	A	*C. strigosus*	0029FS78
			C. odoratus	

(Continued)

Collection Site	Location	Sample	Species	WES Herbarium Number
MC12 (Continued)		B	*C. strigosus*	
			C. odoratus	
		C	*C. strigosus*	
		D	*C. strigosus*	
			C. odoratus	
		E	*C. strigosus*	
			C. odoratus	
MC13	Berrien County, Mich.	A	*C. odoratus*	0030FS78
		B		
		C		
		D		
		E		
IN1	Porter County, Ind.	A	*C. strigosus*	0031FS78
		B		
		C		
		D		
		E		

(Sheet 8 of 8)

APPENDIX E: LEAF TISSUE HEAVY METAL CONTENT ($\mu g\ g^{-1}$) OF *SPARTINA ALTERNIFLORA* SAMPLES

Leaf Tissue Heavy Metal Content ($\mu g\ g^{-1}$) of *Spartina Alterniflora* Samples

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
BM1 A	0.125	0.1177	2.856	0.927	105.060	1.979	267.886	1.102	22.057	0.0138
BM1 B	<0.025	0.0275	3.028	<0.025	94.194	1.101	163.013	0.901	14.802	0.0088
BM1 C	0.150	0.1126	3.103	1.602	222.573	1.552	267.618	1.226	13.651	0.0163
BM1 D	<0.025	0.0201	2.913	3.089	65.394	0.753	105.826	0.402	12.745	0.0113
BM2 A	0.000	0.0477	3.589	3.188	67.871	1.406	79.418	0.377	16.704	0.0113
BM2 B	<0.025	<0.0025	2.603	3.854	84.347	1.114	163.326	4.555	10.973	0.0100
BM2 C	<0.025	<0.0025	2.925	3.350	85.512	2.062	51.912	3.875	10.412	0.0100
BM2 D	<0.025	0.0075	3.956	4.206	113.933	2.116	102.317	<0.075	16.087	0.0175
BM3 A	<0.025	0.0175	2.325	2.025	68.762	1.212	153.412	4.475	6.663	0.0125
BM3 B	<0.025	<0.0025	2.725	4.875	155.512	1.962	218.912	<0.075	30.312	0.0100
BM3 C	<0.025	0.1783	1.600	3.950	100.617	2.158	277.367	1.700	27.550	0.0050
BM3 D	<0.025	0.0058	<0.025	4.882	165.615	2.287	322.851	<0.075	29.845	0.0150
BM4 A	<0.025	0.0433	<0.025	4.925	108.367	1.783	269.867	<0.075	20.050	0.0125
BM4 B	<0.025	0.0433	0.650	3.200	71.617	2.558	66.617	1.675	40.050	0.0100
BM4 C	<0.025	0.1854	<0.025	1.428	145.140	2.179	295.441	0.676	22.733	0.0338
BM4 D	<0.025	<0.0025	<0.025	1.403	88.277	2.004	75.000	0.777	22.983	0.0313
BM5 A	<0.025	0.2586	<0.025	5.931	47.915	2.736	192.309	2.252	6.006	0.0125
BM5 B	<0.025	0.0958	<0.025	5.250	48.617	7.058	179.867	2.250	14.300	0.0125
BM5 C	<0.025	0.1678	1.527	3.731	61.693	3.430	310.315	1.778	19.016	0.0238
BM5 D	<0.025	0.0100	1.100	3.375	63.350	4.550	156.850	1.275	17.412	0.0212
BM6 A	<0.050	0.0225	3.117	3.228	237.415	1.320	12.547	4.583	17.058	0.0138
BM6 B	<0.025	0.0050	2.851	3.052	175.938	0.975	11.131	3.952	19.847	0.0188
BM6 C	<0.025	0.0209	1.564	2.578	160.027	3.111	74.191	1.176	13.313	0.0175
BM6 D	<0.025	0.0209	1.165	4.208	154.426	1.887	77.522	2.179	27.355	0.0100
BM7 A	<0.025	0.0175	0.850	2.226	65.545	4.290	252.289	<0.075	7.041	0.0075
BM7 B	<0.050	0.0100	4.108	4.108	186.072	2.204	250.200	1.553	16.408	0.0075
BM7 C	<0.025	0.0827	2.632	1.905	66.015	1.053	252.982	0.226	13.947	0.0063
BM7 D	<0.025	0.0050	1.500	3.100	103.762	2.087	71.662	3.325	5.863	0.0175
BM8 A	<0.025	0.0801	2.178	4.432	46.157	2.191	36.893	2.917	14.584	<0.0050

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
BM8 B	<0.025	0.0175	2.701	2.451	46.625	1.526	27.364	0.775	24.450	0.0163
BM8 C	<0.025	0.0450	3.752	2.651	86.393	1.851	25.863	1.276	35.955	0.0163
BM8 D	<0.025	<0.0025	4.250	2.650	58.512	0.063	21.537	<0.075	10.313	0.0075
BM9 A	<0.025	0.0408	2.200	4.525	36.867	1.008	44.117	1.350	0.225	0.0100
BM9 B	<0.025	0.0075	1.027	3.255	41.149	1.740	34.139	2.717	9.326	0.0063
BM9 C	<0.025	0.1134	1.638	2.826	38.636	2.610	11.397	0.450	27.064	0.0200
BM9 D	<0.025	0.0000	4.100	1.875	42.512	2.287	11.687	<0.075	4.713	0.0075
BM10 A	<0.025	0.1358	1.500	3.850	70.617	2.833	31.367	1.750	1.050	0.0100
BM10 B	<0.025	0.0125	3.756	4.106	82.974	0.926	27.391	1.427	11.905	0.0038
BM10 C	<0.025	0.0800	2.926	3.477	61.293	2.864	43.684	<0.075	6.591	0.0100
BM10 D	<0.025	0.0533	2.013	4.775	103.867	1.783	48.617	0.975	10.225	0.0100
BM11 A	<0.025	0.1342	2.426	4.364	79.378	1.928	83.131	3.050	16.797	0.0269
BM11 B	<0.025	0.1009	1.926	4.402	44.139	1.734	101.417	2.076	27.564	0.0275
BM11 C	<0.025	0.1883	1.800	3.775	136.867	1.283	40.117	1.875	33.050	0.0125
BM11 D	<0.025	0.0659	1.451	3.552	109.421	1.784	33.884	2.601	19.060	0.0125
BM12 A	<0.025	0.0275	1.075	4.875	103.262	1.262	162.412	4.075	7.363	0.0200
BM12 B	<0.025	0.0625	0.600	2.751	71.873	3.139	109.392	3.089	12.769	0.0038
BM12 C	<0.025	0.0551	0.501	4.507	92.727	2.491	230.684	5.070	29.357	0.0188
BM12 D	<0.025	0.0266	3.287	6.422	87.155	4.114	69.594	0.552	13.108	0.0138
CC1 A	<0.025	0.0175	3.702	4.002	97.561	1.138	56.191	5.078	41.333	0.0150
CC1 B	<0.025	0.3977	3.427	1.251	108.679	3.877	54.177	2.251	27.889	0.0275
CC1 C	<0.025	0.2601	3.152	4.377	114.320	1.688	45.435	4.277	30.078	0.0100
CC1 D	<0.225	0.2300	4.150	1.475	75.012	2.912	28.662	<0.075	26.312	0.0025
CC2 A	<0.025	0.1300	3.613	3.013	98.786	1.038	36.672	2.913	17.378	0.0113
CC2 B	<0.025	0.3058	2.125	3.625	120.617	1.383	76.617	1.850	45.050	0.0050
CC2 C	<0.025	0.1251	3.427	0.925	97.899	2.051	38.869	1.701	41.458	0.0138
CC3 A	<0.025	0.1651	2.701	3.427	101.813	1.338	159.742	1.551	25.325	0.0200
CC3 B	<0.025	0.3833	9.700	6.325	153.867	8.083	120.867	3.875	686.050	0.0100
CC3 C	<0.025	0.1251	2.851	1.126	66.296	2.814	44.685	1.726	26.826	0.0075
CC3 D	<0.025	0.0200	3.702	1.676	113.819	5.415	26.176	2.376	27.326	0.0075
CC4 A	<0.025	0.0475	3.700	<0.025	67.600	2.500	15.275	1.625	18.287	0.0013

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
CC4 B	<0.025	0.0958	2.863	2.475	108.617	3.383	31.617	1.125	40.550	0.0575
CC4 C	<0.025	0.1325	2.900	1.025	209.625	1.875	31.900	2.975	14.125	0.0150
CC4 D	<0.025	0.1226	3.804	1.752	154.417	5.893	20.908	1.702	28.591	0.0125
CC5 A	<0.025	0.0025	2.275	3.925	56.762	1.062	31.412	3.900	11.362	0.0600
CC5 B	0.025	0.0200	3.203	2.878	66.579	1.664	62.225	5.155	14.077	0.0075
CC5 C	<0.025	0.1476	6.331	3.904	1779.378	2.728	26.627	1.226	98.286	0.0063
CC5 D	<0.025	0.0250	4.550	3.075	103.262	1.687	33.662	<0.075	18.812	0.0100
CC6 A	<0.025	0.0659	3.214	2.776	55.144	2.435	31.883	1.251	22.561	0.0575
CC6 B	<0.025	0.0904	1.750	2.613	52.747	1.092	155.369	1.938	47.374	0.0019
CC6 C	<0.025	0.1109	2.201	2.801	44.139	1.784	42.138	<0.075	15.058	0.0125
CC6 D	<0.025	0.0058	1.001	2.951	36.385	2.084	23.704	0.000	2.351	0.0475
CC7 A	<0.025	0.1009	1.563	4.302	32.633	1.484	172.203	0.525	18.553	0.0350
CC7 B	<0.025	0.0975	2.501	1.951	33.029	0.213	99.712	1.151	3.689	0.0125
CC7 C	<0.025	0.0225	3.500	<0.025	63.350	1.725	45.100	1.425	7.588	0.0038
CC7 D	<0.025	0.0100	3.877	2.251	46.036	0.163	45.435	<0.075	4.915	0.0075
CC8 A	<0.025	<0.0025	1.927	1.276	83.346	2.290	21.559	3.453	12.950	0.0025
CC8 B	<0.025	0.0425	2.425	0.500	49.375	<0.113	32.650	1.500	<0.010	0.0175
CC8 C	<0.025	0.0375	3.650	0.850	46.850	0.675	24.200	1.200	12.437	0.0013
CC8 D	<0.025	0.0558	1.600	1.550	38.867	4.158	25.117	1.100	20.800	0.0025
CC9 A	<0.025	0.1159	0.725	2.726	43.889	1.184	40.137	1.676	15.058	<0.0050
CC9 B	0.125	0.0275	2.903	2.127	80.180	0.951	25.375	1.502	18.281	0.0013
CC9 C	0.125	0.0808	0.825	2.050	49.367	0.658	42.367	0.800	22.300	<0.0050
CC9 D	<0.025	0.0408	2.025	3.225	210.367	1.233	14.242	1.125	24.800	0.0075
CC10 A	<0.025	0.1433	2.750	3.575	40.367	2.983	70.117	2.475	4.750	0.0050
CC10 B	<0.025	0.0934	2.340	4.755	117.985	1.760	272.639	1.201	28.579	0.0526
CC10 C	<0.025	<0.0025	3.007	1.451	31.278	0.838	47.186	4.627	4.415	<0.0050
CC10 D	0.175	0.0100	3.078	0.576	41.554	0.738	122.535	5.105	6.119	<0.0050
CC11 A	0.025	<0.0025	1.851	1.976	43.284	0.263	49.437	1.451	5.865	0.0075
CC11 B	0.025	<0.0025	2.225	3.275	44.762	0.337	189.912	4.125	4.363	0.0025
CC11 C	0.175	0.0776	0.375	1.602	76.426	3.478	72.923	1.376	16.929	0.0313
CC11 D	<0.025	0.0150	2.653	4.329	57.080	0.813	142.805	4.429	7.270	0.0025

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
CC12 A	0.050	0.2932	2.481	3.659	76.541	1.479	343.208	1.228	31.266	0.0163
CC12 B	<0.025	0.1880	1.779	5.313	69.010	2.018	325.652	4.574	18.609	0.0013
CC12 C	<0.025	0.1385	1.714	3.804	105.973	1.109	182.299	4.680	19.820	0.0275
CC12 D	<0.025	0.0659	1.126	3.477	91.162	1.934	93.163	4.802	4.377	0.0025
CC13 A	<0.025	0.1560	1.802	3.829	99.466	2.286	144.761	4.555	28.328	<0.0050
CC13 B	<0.025	0.0275	3.052	2.051	87.056	1.463	211.768	1.751	4.090	0.0025
CC13 C	<0.025	0.1376	3.202	2.151	54.877	1.226	87.894	1.751	19.097	0.0013
CC13 D	0.025	0.0458	0.613	3.225	97.367	2.208	188.367	1.625	19.050	0.0075
CC14 A	<0.025	0.0450	4.000	2.450	101.350	1.075	60.850	0.650	15.313	0.0013
CC14 B	<0.025	<0.0025	4.452	2.551	138.582	0.738	82.704	<0.075	7.616	0.0050
CC14 C	<0.025	0.0425	3.700	1.600	60.850	1.200	46.600	1.800	16.512	0.0038
CC14 D	<0.025	0.0175	2.301	1.426	126.163	1.576	22.286	3.552	16.496	0.0038
CC15 A	<0.025	0.1233	2.100	3.850	43.617	1.508	123.117	1.875	8.975	0.0075
CC15 B	<0.025	0.0359	1.763	9.030	81.407	1.309	167.200	0.075	13.057	0.0025
CC15 C	<0.025	0.0577	3.813	3.889	61.064	1.530	116.006	0.477	15.341	<0.0050
CC15 D	<0.025	0.0225	3.627	2.701	61.631	0.425	325.013	1.601	17.521	0.0038
JV1 A	<0.025	0.1378	1.128	<0.025	43.960	1.554	18.797	0.376	15.752	0.0288
JV1 B	<0.025	0.0608	3.188	2.575	61.117	1.808	22.717	0.075	8.000	0.0175
JV1 C	0.475	0.1809	2.889	0.350	122.678	1.059	42.638	0.275	8.429	<0.0050
JV1 D	<0.025	0.1459	2.526	0.825	105.169	1.809	73.153	1.926	25.063	0.0050
JV2 A	0.025	0.0533	0.500	2.500	314.117	1.283	35.367	0.500	63.550	0.0125
JV2 B	<0.025	0.0075	2.126	1.376	56.378	1.426	65.883	1.326	34.955	0.0188
JV2 C	0.150	<0.0025	3.305	0.200	61.355	1.039	29.957	<0.075	6.122	0.0100
JV2 D	<0.025	0.0100	2.076	0.425	93.559	0.713	55.690	4.627	7.166	0.0100
JV3 A	0.050	0.0527	2.633	1.304	106.419	1.605	40.471	0.150	14.030	0.0088
JV3 B	<0.025	0.0250	1.300	0.325	60.762	0.362	34.662	3.800	3.938	0.0050
JV3 C	<0.025	0.0625	2.075	1.225	258.262	1.287	38.912	<0.075	0.388	0.0250
JV3 D	<0.025	<0.0025	2.301	<0.025	69.797	1.288	43.684	<0.075	3.614	0.0075
JV4 A	<0.025	0.0100	2.501	0.575	49.037	0.163	71.948	3.302	7.741	0.0075
JV4 B	0.175	<0.0025	2.300	0.150	41.012	0.512	74.162	1.425	16.062	0.0125
JV4 C	0.050	0.0450	2.177	0.125	118.631	0.413	39.452	3.478	11.649	0.0075

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
JV4 D	<0.025	<0.0025	1.400	0.975	42.262	1.537	53.412	1.400	4.813	0.0100
JV5 A	<0.025	<0.0025	<0.025	1.125	30.762	0.737	7.437	4.375	21.812	0.0050
JV5 B	<0.025	0.0309	0.839	1.754	70.758	1.186	24.140	0.752	11.323	0.0276
JV5 C	<0.025	0.0484	0.938	2.151	105.670	1.459	33.383	0.975	14.057	0.0500
JV5 D	<0.025	<0.0025	2.976	1.176	126.326	<0.113	21.973	<0.075	7.116	0.0075
JV6 A	<0.025	0.0306	0.375	0.575	29.131	0.183	4.594	<0.075	21.061	<0.0050
JV6 B	<0.025	0.1008	0.675	1.775	59.867	0.858	20.417	1.250	14.050	<0.0050
JV6 C	0.025	0.0600	1.425	2.300	97.762	1.787	16.737	4.600	10.563	<0.0050
JV6 D	<0.025	0.0225	2.302	1.326	115.215	1.276	13.914	1.076	25.713	0.0038
JV7 A	<0.025	0.0752	2.457	2.482	135.005	1.555	58.269	0.301	13.052	<0.0050
JV7 B	<0.025	0.0951	2.503	1.827	239.840	0.926	44.895	1.276	12.550	0.0038
JV7 C	<0.025	0.3183	2.808	1.579	193.083	1.729	44.712	<0.075	11.416	0.0038
JV7 D	0.025	0.5834	3.305	1.102	134.051	0.826	39.409	<0.075	12.156	0.0038
JV8 A	<0.025	0.1558	0.900	0.575	110.367	1.208	180.367	1.700	0.750	<0.0050
JV8 B	0.025	0.0550	0.700	2.801	84.635	1.388	49.362	3.464	11.143	0.0013
JV8 C	<0.025	0.1258	2.175	4.450	94.867	1.408	121.617	2.550	14.300	0.0025
JV8 D	0.050	0.1484	1.238	3.727	80.407	1.134	107.671	0.975	21.811	0.0725
JV9 A	<0.025	0.0983	0.350	2.475	151.367	1.833	20.917	1.300	17.800	<0.0050
JV9 B	0.100	0.0125	1.601	1.751	343.434	0.763	23.499	4.752	55.840	0.0075
JV9 C	0.825	0.0375	2.800	1.250	4738.262	2.612	73.662	5.500	101.812	0.0025
JV9 D	<0.025	<0.0025	2.926	1.201	54.290	0.788	8.592	<0.075	3.739	0.0025
JV10 A	<0.025	0.0300	1.225	1.300	84.262	1.637	12.237	3.225	5.138	0.0050
JV10 B	<0.025	<0.0025	2.477	1.451	138.401	0.363	14.127	4.655	6.819	0.0050
JV10 C	<0.025	0.0175	0.425	0.500	43.647	<0.013	17.434	0.775	3.827	0.0100
JV10 D	<0.025	<0.0025	1.513	2.376	69.651	1.559	18.226	0.825	15.308	0.0075
JV11 A	0.125	<0.0025	1.501	3.002	70.048	1.763	9.067	3.402	11.168	0.0050
JV11 B	0.050	<0.0025	2.851	2.276	52.626	1.276	8.704	<0.075	11.993	0.0063
JV11 C	0.025	<0.0025	1.250	1.250	36.850	1.175	10.400	0.600	23.437	0.0013
JV11 D	0.025	<0.0025	<0.025	1.376	51.401	1.351	13.789	0.450	18.406	0.0288
JV12 A	0.050	0.3358	1.250	2.425	3234.117	1.933	22.717	1.675	69.800	0.0025
JV12 B	0.125	0.0400	1.475	0.150	39.100	1.300	7.975	1.075	20.237	0.0062

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
JV12 C	0.075	0.1151	2.226	0.150	78.889	1.651	12.781	1.276	15.020	0.0063
JV12 D	<0.025	0.0551	2.177	0.801	73.924	1.527	7.257	2.828	12.925	0.0038
N01 A	0.050	0.2408	<0.025	3.225	49.117	2.208	50.617	<0.075	11.300	<0.0050
N01 B	<0.025	0.1076	<0.025	1.426	77.928	2.402	46.647	1.176	18.581	0.0288
N01 C	0.275	0.1800	0.650	2.400	50.762	2.487	50.662	3.500	6.813	0.0125
N01 D	0.050	0.7158	0.913	4.950	72.867	3.258	49.367	1.000	20.300	0.0450
N02 A	<0.025	0.0650	2.400	0.225	57.600	1.900	110.600	2.250	19.112	0.0163
N02 B	0.050	0.1333	0.125	3.500	40.867	3.733	61.117	2.150	11.550	0.0125
N02 C	<0.025	0.0476	2.579	1.227	72.459	1.152	70.956	2.278	15.711	0.0188
N02 D	<0.025	0.1552	2.454	3.405	60.441	6.234	138.558	3.130	16.738	0.0188
N03 A	<0.025	0.0376	3.482	1.829	93.387	1.353	164.429	<0.075	11.160	0.0013
N03 B	<0.025	0.0308	1.638	2.451	185.710	1.059	138.186	0.250	12.306	0.0400
N03 C	<0.025	0.1556	3.012	3.489	170.532	2.435	81.677	1.456	20.871	0.0163
N03 D	<0.025	0.0100	3.102	1.876	174.850	1.588	57.441	<0.075	7.241	0.0275
N04 A	<0.025	0.0501	1.977	3.253	51.889	1.814	75.163	3.566	4.142	0.0063
N04 B	0.100	0.0409	2.526	6.828	189.962	1.709	144.939	3.127	31.566	0.0100
N04 C	<0.025	<0.0025	3.927	3.402	72.799	1.888	43.684	4.852	4.890	0.0075
N04 D	<0.025	0.0525	1.376	11.181	105.903	1.026	88.894	0.525	22.224	0.0113
N05 A	<0.025	0.0558	2.725	5.125	48.867	1.658	64.867	3.200	21.300	0.0050
N05 B	<0.025	0.0275	3.075	3.300	91.350	3.200	176.350	1.850	19.062	0.1512
N05 C	<0.025	0.0601	3.003	3.078	53.654	0.726	92.693	0.025	16.454	0.0263
N05 D	0.050	0.0934	0.900	3.302	199.426	2.234	340.037	2.426	28.314	<0.0050
N06 A	<0.025	<0.0025	1.551	2.976	69.047	0.838	189.507	4.002	7.091	0.0075
N06 B	<0.025	0.0358	1.475	2.650	40.117	1.433	169.117	1.675	24.050	0.0025
N06 C	<0.025	0.0708	1.100	2.375	52.867	1.908	179.117	1.825	10.125	0.0125
N06 D	<0.025	0.0559	1.176	2.628	138.255	2.361	128.745	1.802	2.177	0.0075
N07 A	<0.025	0.0383	0.575	2.525	46.117	1.483	33.867	0.925	19.800	0.0075
N07 B	<0.025	0.0184	0.813	3.128	84.451	3.412	48.415	0.300	6.456	0.0075
N07 C	<0.025	0.0308	1.401	3.102	42.388	1.788	14.799	0.050	4.952	<0.0050
N07 D	<0.025	0.1050	3.075	2.225	41.012	2.462	24.162	4.925	6.238	0.0100
N08 A	<0.025	0.0075	0.975	2.001	84.642	1.551	107.654	0.375	19.072	0.0263

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
NO8 B	<0.025	0.0175	3.350	2.775	67.012	2.562	72.162	<0.075	6.063	0.0100
NO8 C	<0.025	0.0025	3.127	2.726	44.372	0.750	17.834	1.476	21.823	0.0063
NO8 D	0.150	0.0125	3.509	2.331	38.446	1.554	18.446	1.353	12.568	0.0063
NO9 A	<0.025	0.0777	3.786	1.906	40.722	2.508	27.182	0.376	12.676	0.0113
NO9 B	<0.025	0.0525	3.402	4.377	50.538	2.514	32.179	<0.075	9.892	0.0025
NO9 C	<0.025	0.1201	4.177	3.177	50.538	2.139	28.677	<0.075	13.019	0.0075
NO9 D	<0.025	0.0801	4.304	2.227	41.892	3.053	27.127	2.603	16.054	0.0388
NO10 A	<0.025	0.3650	4.025	2.075	42.100	2.425	121.350	1.775	13.912	0.0013
NO10 B	<0.025	0.2604	2.904	1.728	29.895	2.679	31.397	1.577	11.405	0.0088
NO10 C	<0.025	0.0300	3.950	6.500	64.512	1.837	31.162	<0.075	11.563	0.0050
NO10 D	<0.025	0.1526	4.727	3.802	55.378	1.901	96.148	0.800	16.521	0.0013
NO11 A	0.225	0.1710	3.166	3.403	2248.866	2.386	84.451	1.777	70.871	<0.0050
NO11 B	<0.025	0.1158	1.425	3.425	86.117	2.283	35.617	1.825	4.250	0.0025
NO11 C	0.050	0.1609	0.713	2.951	189.211	2.435	214.224	0.900	21.811	0.0775
NO11 D	<0.025	0.0633	0.813	2.725	106.117	1.633	47.117	0.775	11.050	0.0100
NO12 A	0.050	0.0183	1.200	1.825	284.117	1.933	214.367	3.225	3.400	0.0050
NO12 B	<0.025	0.0809	0.900	3.952	145.940	2.560	295.014	2.026	8.329	0.0050
NO12 C	<0.025	0.0876	0.926	2.427	115.453	2.440	127.965	3.416	6.994	<0.0050
NO12 D	0.200	0.0958	2.425	2.300	264.117	2.058	294.867	3.125	2.150	0.0050
NY1 A	<0.025	0.7283	1.363	8.075	49.867	0.858	50.617	1.275	29.300	0.0275
NY1 B	0.100	0.0350	3.700	5.200	970.100	1.075	44.100	1.725	43.937	0.0188
NY1 C	<0.025	0.2158	2.125	8.150	61.867	1.158	65.117	1.525	42.800	0.0150
NY1 D	<0.025	0.0450	5.425	9.000	3365.100	1.025	134.850	2.525	101.437	0.0188
NY2 A	<0.025	0.1076	2.853	5.205	89.690	1.527	45.395	1.051	42.230	0.0613
NY2 B	<0.025	0.0125	2.379	5.358	82.887	3.317	43.478	3.806	16.337	0.0501
NY2 C	<0.025	0.0350	1.852	4.555	84.935	1.251	36.386	1.251	19.882	0.0413
NY2 D	<0.025	0.0000	1.252	5.183	113.270	1.903	33.901	0.826	36.242	0.0488
NY3 A	0.075	0.2586	1.226	7.057	49.666	1.009	12.955	0.701	27.828	0.0050
NY3 B	0.200	0.2554	1.127	5.483	191.387	3.105	52.679	1.477	30.984	0.0513
NY3 C	0.151	0.2912	3.941	8.961	209.689	3.489	58.333	1.280	29.556	0.0238
NY3 D	0.050	0.4056	3.630	8.788	140.310	4.632	19.680	2.629	96.082	0.0313

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
NY4 A	<0.025	0.1482	5.249	13.059	243.697	2.762	10.849	2.009	61.464	0.0138
NY4 B	<0.025	0.3675	7.350	7.975	1885.762	4.187	42.412	5.750	52.062	0.0150
NY4 C	<0.025	0.2375	3.975	9.675	173.012	3.037	19.687	5.975	69.312	0.0175
NY4 D	0.075	0.2758	6.770	8.074	479.037	4.137	35.958	1.379	27.771	0.0263
NY6 A	<0.025	0.0651	3.756	6.209	127.541	26.765	29.895	1.452	30.483	0.0163
NY6 B	<0.025	0.0800	3.575	5.850	2863.262	18.312	58.912	2.400	77.812	0.0150
NY6 C	<0.025	0.4825	4.475	6.875	258.262	5.087	62.412	6.125	33.812	0.0150
NY6 D	<0.025	0.0162	2.250	4.375	255.694	8.331	86.656	4.275	17.344	0.0237
NY7 A	<0.025	0.0434	1.351	5.528	52.143	1.984	27.630	1.726	32.316	0.0125
NY7 B	<0.025	0.1084	2.865	7.207	68.685	2.286	49.917	1.151	39.089	0.0425
NY7 C	<0.025	0.0934	2.689	8.929	57.395	2.360	50.142	1.126	49.325	0.0425
NY7 D	<0.025	<0.0025	2.528	3.253	45.646	1.802	20.145	1.351	29.967	0.0138
NY8 A	<0.025	0.0983	2.038	11.675	120.867	2.133	24.342	2.250	58.550	0.0175
NY8 B	<0.025	0.0900	3.900	12.825	134.512	1.137	23.612	6.275	71.062	0.0125
NY8 C	<0.025	0.0372	3.250	9.550	103.012	1.012	21.612	5.850	59.312	0.0125
NY8 D	<0.025	0.0651	3.529	7.207	1561.662	1.426	34.885	4.004	99.537	0.0163
NY9 A	<0.025	0.0534	1.127	11.172	83.283	1.186	49.215	2.154	88.727	0.0125
NY9 B	<0.025	0.1101	2.578	7.758	57.407	0.951	17.743	2.302	123.061	0.0188
NY9 C	<0.025	0.1403	2.730	6.288	76.002	1.303	11.623	0.952	75.088	0.0188
NY9 D	<0.025	0.0926	4.079	8.759	101.864	0.413	15.803	0.751	114.677	0.0250
NY10 A	<0.025	0.0803	3.713	6.874	74.109	1.681	44.757	1.330	12.657	0.0213
NY10 B	<0.025	0.0125	2.951	3.802	83.054	1.238	67.696	<0.000	6.466	0.0175
NY10 C	<0.025	0.0679	3.645	3.972	29.764	2.539	67.696	<0.000	6.466	0.0138
NY10 D	<0.025	0.1525	2.850	3.900	40.262	1.637	34.412	4.025	8.813	0.0150
NY11 A	<0.025	0.0275	2.051	2.851	41.033	0.638	7.891	<0.000	10.393	0.0150
NY11 B	<0.025	<0.0025	1.775	2.425	39.262	1.762	8.812	<0.000	6.588	0.0175
NY11 C	<0.025	<0.0025	2.202	2.703	186.949	0.863	11.349	6.956	4.922	0.0150
NY11 D	<0.025	<0.0025	2.400	2.925	53.012	0.362	25.162	<0.000	7.388	0.0200
NY12 A	<0.025	0.0333	1.100	3.150	150.117	0.758	56.867	3.125	15.300	0.0125
NY12 B	<0.025	0.0483	1.100	4.400	119.617	1.283	42.867	3.375	14.300	0.0150
NY12 C	0.050	0.0125	1.476	3.577	135.668	1.051	37.869	2.326	39.457	0.0263
NY12 D	<0.025	0.0483	1.750	4.550	120.617	1.158	92.367	1.925	23.050	0.0200

APPENDIX F: MEAN HEAVY METAL UPTAKE ($\mu g\ m^{-2}$) OF *SPARTINA ALTERNIFLORA* IN NATURAL MARSHES

Mean Heavy Metal Uptake ($\mu g\ m^{-2}$) of *Spartina alterniflora* in Natural Marshes

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
BM1	45.1	51.7	2513	1202	87,798	1102	159,255	715	13,698	10.09
BM2	<0.1	8.4	2203	2552	60,465	1114	74,605	1832	9,131	8.17
BM3	<0.1	29.6	708	1681	51,146	837	107,462	735	10,225	4.35
BM4	<0.1	19.8	103	1283	50,611	1192	64,586	518	15,220	12.91
BM5	<0.1	163.7	733	4861	58,179	4181	231,657	2006	14,319	18.67
BM6	<0.1	19.6	2295	3431	186,599	2410	56,871	2822	19,876	18.04
BM7	<0.1	20.4	1782	2097	80,523	1732	156,931	837	8,305	5.45
BM8	<0.1	22.9	2542	2315	45,720	1051	21,848	833	16,607	8.79
BM9	<0.1	40.0	2032	3847	43,560	1871	34,773	1762	9,704	11.06
BM10	<0.1	59.3	2105	3273	63,756	1760	30,566	836	5,892	6.90
BM11	<0.1	114.0	1902	4035	70,161	1646	77,572	2240	23,803	22.62
BM12	<0.1	53.8	1291	5031	104,249	3065	170,830	4088	17,045	15.38
CC1	34.9	154.3	2316	1670	63,680	1637	29,945	1791	19,954	10.33
CC2	<0.1	123.0	1945	1639	68,425	962	33,249	1375	22,635	6.34
CC3	5.4	92.1	2668	1638	63,409	2632	45,915	1407	90,274	6.34
CC4	<0.1	52.0	1756	632	71,445	1800	12,544	1000	12,461	9.23
CC5	2.9	17.4	1442	1182	175,063	637	14,298	957	12,479	6.19
CC6	<0.1	25.7	790	1158	18,563	783	21,587	490	7,226	13.09
CC7	<0.1	44.9	1730	1651	27,975	695	71,084	519	7,047	12.31
CC8	<0.1	13.4	1207	507	28,179	814	11,824	971	5,761	2.10
CC9	35.2	30.8	919	1325	55,759	521	14,944	643	10,885	1.39
CC10	25.8	36.2	1572	1619	38,586	884	87,864	1773	7,889	11.57
CC11	33.1	15.1	1961	3095	53,564	869	131,604	3347	6,829	6.42
CC12	1.9	40.6	433	1113	21,828	470	59,929	1101	4,125	1.97
CC13	2.5	29.1	758	981	30,384	635	58,586	815	5,820	1.10
CC14	<0.1	12.4	1761	960	49,867	533	26,189	668	6,549	1.71
CC15	<0.1	34.1	1762	1977	38,656	692	120,955	634	8,669	2.12
JV1	25.5	58.2	1432	792	41,562	910	20,738	360	7,550	7.40
JV2	39.1	13.8	1460	831	102,058	813	31,853	984	10,810	9.04
JV3	26.9	80.4	4919	1659	305,044	2772	91,728	1514	11,778	28.90
JV4	63.7	17.1	2771	797	86,717	1220	82,081	3154	12,884	13.57

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
JV5	<0.1	36.8	2104	2752	150,093	1503	39,129	2627	23,782	42.02
JV6	4.1	53.2	1787	1683	101,770	1287	16,829	1728	22,164	2.18
JV7	5.2	169.4	1494	849	89,607	595	23,490	199	6,454	1.61
JV8	6.6	62.9	600	1245	53,568	698	64,841	1273	4,579	3.76
JV9	164.6	38.3	1376	1448	966,128	1281	24,704	2097	32,819	2.02
JV10	<0.1	12.5	1586	1782	92,911	1063	20,049	2271	10,560	9.18
JV11	49.5	<0.1	1217	1803	49,253	1289	10,029	928	14,972	11.62
JV12	42.6	78.0	1165	485	436,306	1014	7,690	1085	17,168	3.16
NO1	22.7	99.7	117	930	22,736	876	16,330	456	5,349	8.71
NO2	10.3	67.3	1304	1352	41,185	2068	65,448	1703	11,388	11.70
NO3	<0.1	24.9	1625	1265	81,929	814	75,764	129	6,851	10.77
NO4	17.1	15.9	1017	2665	51,505	681	42,236	1256	8,020	3.78
NO5	3.4	16.0	647	1044	20,893	540	44,567	572	5,843	11.35
NO6	<0.1	39.0	1283	2552	67,629	1544	162,218	2214	11,416	7.09
NO7	<0.1	26.6	833	1521	30,989	1344	17,456	893	4,668	3.59
NO8	22.7	8.4	2071	1835	44,319	1309	42,646	471	9,681	8.97
NO9	<0.1	42.3	2115	1531	24,314	1423	15,450	533	7,099	9.66
NO10	<0.1	90.3	1802	1650	22,245	1020	31,312	468	6,177	1.95
NO11	43.5	106.8	1026	2447	361,910	1781	93,765	1011	17,756	27.17
NO12	55.1	61.2	1112	1986	148,130	1748	172,469	2347	3,987	2.47
NY1	32.7	118.4	2350	4744	792,682	719	45,964	1225	36,452	13.33
NY2	<0.1	25.0	1533	3864	71,159	1545	29,951	1347	21,093	37.71
NY3	71.0	201.8	1679	4788	97,472	2207	22,022	1131	35,468	19.69
NY4	12.8	170.0	3899	6068	525,236	2311	18,549	2340	32,212	11.53
NY6	<0.1	85.8	1516	2506	287,482	5251	27,115	1759	15,310	7.66
NY7	<0.1	21.5	879	2101	19,705	730	13,011	444	12,954	10.23
NY8	<0.1	51.5	2268	7000	453,850	1026	19,442	3137	53,903	10.64
NY9	<0.1	119.0	2846	9875	85,882	1174	24,260	1664	106,151	20.46
NY10	<0.1	26.3	1241	1583	25,398	638	20,726	535	3,480	6.64
NY11	<0.1	6.0	2317	2989	90,441	1047	14,832	1730	7,858	18.74
NY12	5.1	21.9	773	2283	72,931	618	33,962	1518	12,274	10.20

APPENDIX G: HEAVY METAL CONTENT ($\mu g\ g^{-1}$)
OF *CYPERUS* SPECIES

Heavy Metal Content ($\mu g\ g^{-1}$) of *Cyperus* Samples

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
DE1 A	0.100	0.0767	<0.100	5.500	126.400	6.967	74.967	<0.300	42.567	0.2000
DE1 B	<0.100	0.2367	0.800	6.500	117.400	7.767	62.267	0.433	122.667	0.0500
DE1 C	<0.100	0.0367	0.100	5.200	103.400	5.067	68.367	<0.300	69.767	0.0200
DE1 D	<0.100	0.3267	1.400	9.100	146.400	7.167	93.667	3.433	122.667	0.0500
DE1 E	<0.333	0.1889	<0.333	<0.333	120.667	11.889	66.222	<1.000	103.222	0.1667
DE2 A	<0.250	1.6417	4.750	0.250	256.000	18.167	205.167	<0.250	65.917	0.1000
DE2 B	<0.200	0.1733	2.200	<0.200	108.800	13.533	226.333	<0.600	79.533	0.1600
DE2 C	<0.200	0.1933	4.800	5.000	156.800	16.533	139.933	<0.600	104.933	0.1000
DE2 D	<0.100	0.0267	3.900	12.000	136.400	7.667	244.167	1.633	53.667	0.0500
DE2 E	<0.100	0.1367	<0.100	4.100	91.400	12.767	77.067	<0.300	70.567	0.0100
DE3 A	<0.333	0.3889	<0.333	6.667	146.333	23.889	222.889	<1.000	63.889	0.2000
DE3 B	<0.025	0.1370	D*	3.634	87.820	6.558	114.829	2.540	38.012	0.1654
DE3 C	<0.025	0.5895	D	4.447	110.655	8.671	87.085	4.085	36.935	0.0075
DE3 D	<0.025	0.4317	D	4.150	112.850	6.967	88.542	3.258	43.167	0.0075
DE3 E	<0.025	0.4553	D	4.837	106.366	3.926	65.205	2.164	43.776	<0.0050
DE4 A	<0.050	0.2483	D	8.000	125.700	3.733	84.583	7.467	48.333	0.0100
DE4 B	<0.025	0.3819	D	8.604	105.653	2.968	47.315	2.410	59.687	0.0175
DE4 C	<0.025	0.1867	D	5.150	86.350	3.442	103.792	3.058	32.167	0.0125
DE4 D	<0.025	0.1099	4.329	5.111	85.173	3.572	76.484	0.687	31.312	0.0081
DE4 E	<0.025	0.4000	D	6.212	89.780	4.075	56.404	2.513	43.253	0.0100
DE5 A	<0.025	0.0133	17.200	9.652	76.763	23.359	132.063	0.993	16.475	<0.0050
DE5 B	<0.025	0.2293	D	6.328	100.400	3.018	72.578	1.309	27.931	0.0075
DE5 C	<0.025	0.2672	<0.025	7.966	99.800	3.023	72.186	2.964	35.488	0.0075
DE5 D	<0.025	0.2020	0.451	6.309	101.252	2.520	95.685	1.360	27.708	0.0075
DE5 E	<0.025	0.1109	2.002	5.953	97.519	2.028	133.637	0.392	41.263	0.0087
DE6 A	<0.025	0.0817	2.778	9.234	138.989	3.896	58.851	2.636	31.448	<0.0050
DE6 B	<0.050	0.4233	2.400	8.850	135.200	15.833	101.083	2.267	40.833	0.0150
DE6 C	<0.050	0.4100	1.054	6.526	134.237	4.702	75.385	0.971	47.021	0.0100

(Continued)

* D = sample deleted.

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
DE6 D	<0.025	0.1192	1.150	6.400	87.100	4.567	25.792	2.058	24.417	0.0075
DE6 E	<0.025	0.2392	2.300	7.200	162.350	4.242	88.792	2.208	38.667	0.0075
DE7 A	<0.025	0.2095	1.903	8.963	106.510	4.924	22.776	2.287	74.528	<0.0050
DE7 B	<0.025	0.2367	1.800	8.575	108.350	5.942	23.742	2.558	69.167	0.0050
DE7 C	<0.050	0.2001	3.389	8.675	104.572	4.651	24.197	2.165	78.420	<0.0100
DE7 D	<0.025	0.1968	1.376	4.752	105.403	2.443	50.317	2.460	21.177	0.0025
DE7 E	<0.050	0.3973	1.414	7.273	82.020	6.751	19.276	1.582	65.993	0.0253
DE8 A	<0.025	0.2625	<0.025	7.322	79.338	5.960	66.993	0.786	91.692	0.0050
DE8 B	<0.025	0.4252	1.278	6.391	110.877	5.856	98.538	0.610	130.994	<0.0050
DE8 C	<0.025	0.2505	<0.025	7.617	98.140	5.396	87.020	0.687	103.486	<0.0050
DE8 D	<0.050	0.2190	<0.050	4.514	92.477	3.594	80.324	<0.150	111.668	<0.0100
DE8 E	<0.050	0.2140	1.555	5.065	117.553	5.851	113.424	<0.150	127.716	<0.0100
DE9 A	<0.025	0.0367	1.127	8.438	99.750	4.098	103.447	0.885	99.065	<0.0050
DE9 B	<0.025	0.1268	<0.025	2.102	56.907	2.144	69.111	0.459	45.212	<0.0050
DE9 C	<0.025	<0.0025	0.776	6.294	88.232	4.173	116.967	0.759	84.293	0.0100
DE9 D	<0.025	0.4192	1.325	4.900	88.100	3.867	138.792	1.983	88.417	<0.0050
DE9 E	<0.025	0.2133	1.310	3.980	97.834	8.279	127.750	1.998	55.835	0.0025
IN1 A	<0.050	1.7733	0.750	6.900	107.200	2.533	37.933	4.717	94.833	<0.0100
IN1 B	<0.025	0.4344	<0.025	7.929	95.648	3.018	107.846	3.735	56.445	0.0075
IN1 C	<0.025	1.3612	2.579	4.331	77.967	4.023	57.876	3.238	84.794	0.0050
IN1 D	<0.025	1.7801	0.901	4.204	82.282	2.135	58.141	4.621	93.427	<0.0050
IN1 E	<0.025	0.8429	<0.025	7.286	100.250	5.850	57.878	3.514	68.019	0.0200
MC1 A	<0.050	0.6112	3.056	13.978	325.326	15.055	228.632	11.197	69.765	0.0075
MC1 B	<0.025	0.3605	2.278	7.361	158.325	7.524	204.144	8.650	36.117	0.0038
MC1 C	<0.025	0.2182	2.232	9.554	185.895	6.231	211.723	8.538	41.186	0.0088
MC1 D	<0.025	0.6209	1.152	9.815	157.824	6.122	94.479	4.710	59.652	0.0013
MC1 E	<0.050	0.2483	5.869	8.368	218.485	7.959	197.456	8.631	36.573	<0.0100
MC2 A	<0.025	0.3303	1.552	8.433	139.227	5.843	149.737	6.244	34.097	<0.0050
MC2 B	<0.025	0.2452	1.301	8.959	121.209	5.993	133.971	7.020	36.349	0.0038
MC2 C	<0.050	0.2510	<0.050	10.542	117.144	7.907	155.296	10.417	25.176	<0.0100
MC2 D	<0.025	0.1601	1.751	6.453	152.414	5.865	288.202	5.865	34.830	<0.0050

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
MC2 E	<0.025	0.1447	3.040	7.906	156.586	4.242	217.763	4.865	38.145	<0.0050
MC3 A	<0.025	0.1152	2.328	9.815	213.157	4.394	91.725	2.717	58.650	<0.0050
MC3 B	<0.050	0.2405	1.002	10.621	175.526	4.785	100.376	12.199	137.901	<0.0100
MC3 C	<0.050	0.2156	0.301	10.331	115.020	8.400	103.485	7.297	51.279	<0.0100
MC3 D	<0.050	0.0802	3.507	12.525	110.897	2.630	77.330	4.785	93.813	0.0125
MC3 E	<0.025	0.3600	2.429	11.264	140.382	6.425	98.697	5.605	82.575	0.0131
MC4 A	<0.050	0.1254	<0.050	6.419	190.246	3.786	210.807	8.601	26.711	<0.0100
MC4 B	<0.050	0.1603	1.904	8.216	119.414	5.235	108.392	3.131	54.734	0.0075
MC4 C	<0.100	0.4008	2.605	9.319	101.553	6.263	136.623	3.156	57.365	<0.0200
MC4 D	<0.050	0.0951	2.052	9.710	152.327	7.382	153.829	6.532	47.673	<0.0100
MC4 E	<0.025	0.2994	2.043	9.381	143.926	4.090	145.435	3.673	41.754	0.0067
MC5 A	<0.050	0.1369	1.166	8.012	85.370	4.336	396.222	8.443	77.713	0.0076
MC5 B	<0.050	0.1353	2.555	8.317	139.955	4.083	160.496	0.827	27.680	0.0125
MC5 C	<0.050	0.1602	0.901	7.758	150.826	3.979	120.295	5.881	36.662	0.0325
MC5 D	<0.050	1.1850	1.950	9.150	131.675	8.075	106.175	6.975	73.625	0.0225
MC5 E	<0.025	0.0951	3.565	9.545	169.504	4.435	132.977	2.421	47.879	0.0081
MC6 A	<0.050	0.3850	2.650	16.250	132.675	2.875	60.675	6.275	176.125	0.0125
MC6 B	<0.025	0.4183	3.82	11.799	152.643	3.394	90.018	2.643	69.952	0.0038
MC6 C	<0.050	0.2402	4.454	12.763	83.258	2.027	39.364	2.377	79.705	<0.0100
MC6 D	<0.025	0.5556	2.628	10.010	111.949	43.556	101.689	3.691	73.636	0.0038
MC6 E	<0.025	0.2708	3.737	13.205	147.747	2.525	69.649	12.549	91.189	0.0025
MC7 A	<0.050	0.3273	1.158	14.099	120.519	3.600	115.987	7.779	22.784	<0.0100
MC7 B	<0.050	0.3600	2.950	9.700	73.675	5.175	52.675	4.475	116.125	<0.0100
MC7 C	<0.050	0.2056	0.953	7.272	74.398	2.633	35.030	9.303	77.357	0.0176
MC7 D	<0.050	0.0501	1.503	9.820	69.314	3.081	41.308	5.536	100.827	<0.0100
MC7 E	<0.025	0.4990	3.578	6.847	66.715	4.190	74.321	5.211	181.150	0.0013
MC8 A	<0.050	0.4254	3.504	20.621	417.593	6.031	417.593	4.980	120.245	<0.0100
MC8 B	<0.125	0.1385	4.030	10.202	204.471	3.589	189.358	0.189	93.514	<0.0025
MC8 C	<0.050	0.6783	3.150	19.350	245.200	5.833	361.583	8.567	108.333	0.0150
MC8 D	0.025	0.3697	4.882	11.467	548.423	7.378	495.535	6.718	86.296	0.0175
MC8 E	0.125	0.4982	4.732	15.423	572.446	6.773	405.446	14.109	110.729	0.0138

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
MC9 A	0.025	0.3034	4.037	13.691	112.926	3.573	35.945	1.367	86.071	0.0063
MC9 B	<0.025	0.3681	2.203	15.248	181.360	6.222	51.164	2.717	112.481	<0.0050
MC9 C	<0.025	0.4602	1.776	14.607	106.141	4.015	34.355	1.463	91.108	<0.0050
MC9 D	<0.050	0.4910	1.653	15.982	734.644	85.195	59.294	2.931	D	<0.0100
MC9 E	0.025	0.2976	2.117	13.900	155.254	3.558	47.399	3.292	100.039	<0.0050
MC10 A	<0.025	0.0350	0.876	6.957	219.557	4.417	236.324	3.716	70.383	<0.0050
MC10 B	0.150	0.1168	2.653	10.961	217.317	3.846	127.669	6.014	59.977	0.0075
MC10 C	<0.025	0.0150	0.826	8.863	141.800	5.245	207.899	1.965	44.880	0.0088
MC10 D	<0.025	0.1101	0.025	12.262	157.495	4.042	116.704	4.867	33.846	0.0138
MC10 E	<0.025	0.1226	0.626	10.235	228.066	2.640	115.953	3.291	48.861	0.0088
MC11 A	0.325	0.1825	4.200	7.150	839.087	2.862	172.087	5.687	51.562	<0.0050
MC11 B	<0.142	0.6000	0.286	14.429	764.786	2.071	207.643	1.643	87.500	<0.0285
MC11 C	0.669	0.2285	6.522	9.197	694.649	<0.083	101.282	2.230	117.503	<0.0333
MC11 D	<0.111	0.3460	<0.111	18.973	1893.248	4.967	145.480	4.074	156.529	<0.0222
MC11 E	0.700	0.4600	<0.010	8.100	498.350	2.350	125.350	<0.300	169.250	<0.0200
MC12 A	<0.142	1.3150	7.370	23.988	55.419	10.188	29.697	<0.428	314.835	<0.0285
MC12 B	<0.100	1.5400	<0.100	13.700	69.350	10.450	38.150	7.850	177.250	<0.0200
MC12 C	0.250	1.2813	<0.050	11.211	66.742	2.528	18.243	1.527	105.731	<0.0100
MC12 D	<0.066	2.5844	5.133	11.800	76.267	6.578	28.578	5.022	237.111	<0.0133
MC12 E	<0.025	3.2749	2.828	16.917	118.719	2.044	37.829	3.011	206.123	<0.0050
MC13 A	<0.111	0.0337	<0.111	16.854	74.551	13.539	136.348	0.955	141.854	<0.0222
MC13 B	<0.050	0.2302	<0.050	14.314	87.262	18.493	107.783	11.887	70.195	<0.0100
MC13 C	<0.133	0.3467	<0.133	18.800	81.800	3.800	175.133	1.667	100.333	0.1533
MC13 D	0.175	0.5594	1.726	9.880	73.387	3.118	54.069	3.010	82.208	0.0050
MC13 E	0.150	0.4532	1.252	11.242	157.574	4.745	184.114	2.066	71.920	<0.0050
ME1 A	<0.050	0.1035	<0.050	2.655	77.355	1.987	550.586	4.025	87.508	0.0100
ME1 B	<0.100	0.2075	<0.100	4.217	119.880	6.191	319.444	2.644	110.107	0.0201
ME1 C	0.351	0.0050	<0.050	6.012	189.554	4.434	471.618	0.777	118.863	0.0125
ME1 D	0.250	<0.0050	4.104	6.006	124.299	3.829	357.032	<0.150	95.220	0.0125
ME1 E	<0.025	<0.1596	5.915	5.840	133.434	1.345	443.400	2.590	130.744	0.0175
ME2 A	<0.100	<0.0100	9.018	6.313	95.541	2.555	596.142	<0.300	69.389	<0.0200

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
ME2 B	<0.050	0.0351	3.457	5.311	48.272	4.634	207.089	3.783	80.286	<0.0100
ME2 C	<0.100	<0.0100	4.500	5.400	125.400	0.000	442.167	7.433	95.667	<0.0200
ME2 D	<0.071	<0.0071	0.714	6.143	131.000	2.976	380.833	2.381	101.190	0.0429
ME2 E	<0.050	0.3387	5.756	5.255	210.911	2.736	189.273	3.070	71.405	<0.0100
ME3 A	<0.106	0.0706	2.754	18.144	203.814	<0.053	524.541	6.709	81.532	<0.0213
ME3 B	0.101	0.1677	3.823	26.761	84.909	2.985	311.033	11.301	27.934	0.0302
ME3 C	<0.100	0.0500	4.200	8.500	175.350	2.950	438.350	2.750	100.250	0.0050
ME3 D	<0.100	0.2467	10.200	8.900	155.400	4.967	213.167	8.333	155.667	<0.0200
ME3 E	<0.050	0.2833	6.650	3.800	77.700	1.033	178.583	5.267	41.833	0.0100
ME4 A	<0.050	0.2355	2.906	5.461	145.967	1.779	272.291	0.626	111.849	0.0075
ME4 B	<0.025	0.1702	3.128	4.179	119.207	2.290	239.327	1.139	55.868	0.0038
ME4 C	<0.066	0.1178	8.000	3.533	66.933	4.311	102.111	3.622	110.444	<0.0133
ME4 D	<0.025	0.0776	2.603	2.853	125.963	3.716	152.990	1.768	27.340	0.0038
ME4 E	<0.050	<0.0050	3.800	4.900	102.675	2.725	181.175	2.025	47.625	0.0025
ME5 A	<0.025	0.2096	2.480	3.307	123.848	4.325	197.938	4.041	57.031	0.0100
ME5 B	<0.050	0.0785	2.455	2.906	119.940	2.199	248.580	1.570	61.456	<0.0200
ME5 C	<0.025	0.1627	3.178	4.304	114.452	3.766	282.620	1.614	72.385	0.0113
ME5 D	0.050	0.1339	2.861	2.108	103.614	2.092	396.670	2.175	90.194	<0.0100
ME5 E	<0.050	0.1893	2.756	3.357	170.541	1.737	231.045	2.021	77.989	<0.0100
ME6 A	<0.025	0.1826	4.777	7.054	103.389	3.764	194.185	0.513	137.881	0.0113
ME6 B	0.100	0.1326	2.726	5.928	132.404	4.765	272.474	2.689	106.116	0.0163
ME6 C	<0.025	1.0817	1.875	4.225	106.100	3.367	158.792	1.008	121.917	0.0025
ME6 D	<0.050	1.5865	4.860	13.727	202.605	6.947	239.061	3.975	280.394	0.0351
ME6 E	<0.025	0.4796	2.052	6.982	118.969	5.948	206.248	2.636	136.803	<0.0050
MW1 A	<0.100	0.2276	7.329	<0.100	83.735	1.071	291.332	5.756	32.697	<0.0200
MW1 B	<0.050	0.4538	4.755	5.455	249.950	3.887	161.245	2.269	83.917	<0.0100
MW1 C	<0.100	0.0696	5.532	0.000	79.749	1.427	238.170	7.864	28.045	0.0209
MW1 D	<0.050	0.7162	1.011	5.713	260.566	2.713	107.263	3.455	127.233	0.0051
MW1 E	<0.050	0.2584	4.277	6.203	185.014	3.560	174.919	5.495	84.867	0.0350
MW2 A	<0.050	<0.0050	4.920	1.506	51.556	20.331	147.942	<0.300	8.584	<0.0100

(Continued)

Site	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Hg
MW2 B	0.267	0.3449	0.067	0.935	332.043	6.854	263.129	1.09C	15.131	0.0134
MW2 C	0.334	0.4292	<0.166	2.007	127.759	<0.083	96.767	<0.500	43.423	0.0167
MW2 D	<0.100	0.3867	<0.100	<0.100	383.400	2.367	339.167	<0.300	22.267	0.0200
MW2 E	<0.050	0.1301	2.052	6.006	57.232	3.979	240.916	1.977	92.217	0.0075

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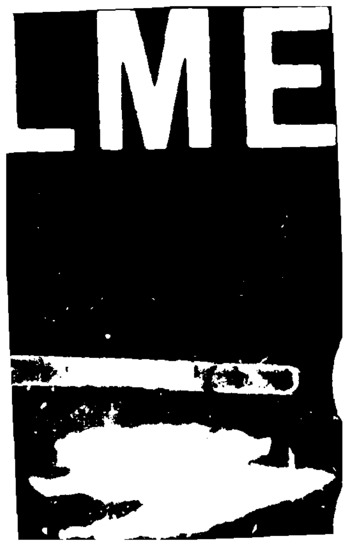
Field survey of heavy metal uptake by naturally occurring saltwater and freshwater marsh plants : final report / by John W. Simmers ... [et al.] (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station.) -- Vicksburg, Miss. : The Station, 1981.
161p. in various pagings : ill. ; 27 cm. --
(Technical report / U.S. Army Engineer Waterways Experiment Station ; EL-81-5.)
Cover title.
"June 1981."
"Prepared for Office, Chief of Engineers, U.S. Army, under Dredging Operations Technical Support Program."
"Available from National Technical Information Service, Springfield, Va. 22161.
Bibliography: p.63-64.

1. Great Lakes. 2. Marshes. 3. Plants. 4. Plants, Effect of heavy metals on. 5. Sedimentation and deposition. I. Simmers, John W. II. United States. Army. Corps of Engineers, Office of the Chief of

Field survey of heavy metal uptake by naturally occurring saltwater and freshwater marsh plants : ... 1981.
(Card 2)

Engineers. III. United States. Army Engineer Waterways Experiment Station. Environmental Laboratory. V. Title VI. Series: Technical report (United States. Army Engineer Waterways Experiment Station) ; EL-81-5.
TA7.W34 no.EL-81-5


LME